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Development of Basic Data & Knowledge Regarding Organic Removal Capabilities of Commercially Available Home Water Treatment Units Utilizing Activated Carbon: Interim Phase 2 Report

Gulf South Research Inst.
New Orleans, LA

Prepared for

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Interim Phase 2 Report to Criteria and Standards Division Office of Drinking Water

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Frank Bell, Project Officer: This is the main Phase 2 report.

16. ABSTRACT

An extensive study of commercially available home water treatment units has been conducted over a 3-year period to examine organics reduction and microbiological factors.

Phase 2 addressed the testing of the bulk of the home treatment units (a total of 30 commercially available units and one experimental unit in both Phases 1 and 2). Before and after filter tests were run for trihalomethanes (THMs), non-purgeable total organic carbon (NPTOC), standard plate count (SPC) bacteria, endotoxin, silver levels (where appropriate) and other perpheral tests. Data and discussions are provided on THM reduction efficiencies, microbiological effects, the lack of bacteriostatic effect from silver and silver effluent levels for the individual units.

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July 1, 1980

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DEVELOPMENT OF BASIC DATA AND KNOWLEDGE REGARDING ORGANIC REMOVAL CAPABILITIES OF COMMERCIALLY AVAILABLE HOME WATER TREATMENT UNITS UTILIZING ACTIVATED CARBON

Final Report - Phase 2

Submitted to:

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FOREWORD

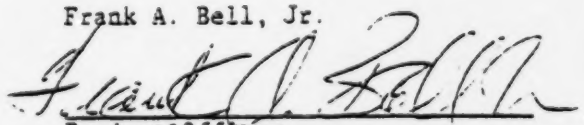
In response to public concern over organics in drinking water, EPA has contracted with GSRI to develop basic data and information on the performance of a variety of small home treatment units with respect to removal of organics and to bacterial/endotoxin aspects. The following report represents second phase testing of 25 additional units using New Orleans tap water and the testing protocol based on Phase 1 results (May 10, 1979, Phase 1 Report).

With one unit overlapping between Phase 1 and 2, the total number of units tested was 31. This kind of coverage will give the consumer, consumer advisory agencies, and others a broad, solid background as to the efficiency of home treatment units for removing trihalomethanes and other organics, and as to bacterial, endotoxin, and other pertinent aspects.

The Water Quality Improvement Standards and Certification Council (WQISCC), an organization representing water filter manufacturers, has reviewed and consulted on the project as it has proceeded. A representative of the faucet-unit manufacturers has also reviewed the Phase 2 report. WQISCC has requested that it be made clear that many, if not most, of the test units have not been designed to remove the trihalomethanes and other organic chemical or microbiological parameters being measured. Most of the activated carbon home water treatment units have been designed to remove taste and odor only. In this study, many are being tested beyond their claims because consumers and responsible government bodies have a need to know their efficacy for organics removal.

Phase 3 of this contract, to be completed by early 1981, will cover the testing of six additional units, including an ozonator, two distillers, and two reverse-osmosis units. Spiking tests with a variety of organic chemicals will also be run on a selection of activated carbon and other units; the focus will be on trichloroethylene, tetrachloroethylene, and similar chemicals found in some groundwaters. Investigations at field locations (Miami, Florida; Detroit, Michigan; Atlanta, Georgia; and Pico Rivera, California) and at three home installations will be completed and described in the Phase 3 report.

Frank A. Bell, Jr.



Project Officer
Criteria and Standards Division
Office of Drinking Water (WH-550)

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The reviews and comments of the various EPA study groups and consultants are valued and acknowledged.

The efforts of many GSRI staff members in the collection and analysis of samples and data review are appreciated; valuable contributions were made by A. Lasome, C. Littleton, G. Cawley, and A. Shoichet. Special appreciation is due the Technical Publications staff, P. Uffelman, J. Harrell, S. Besson, and J. Hamaker.

SECTION 1

INTRODUCTION

Several recent research reports (1,2) have indicated that drinking water produced by many municipal water companies contains trace amounts of organic compounds. Many of these compounds have been shown to be toxic or even carcinogenic and mutagenic at high concentrations. The presence of any toxic compounds in drinking water is cause for public concern. This concern has prompted a series of research projects designed to assess the scope of the problem of organics in drinking water (3) and to suggest ways to alleviate the problem (4-6). Many manufacturers offer treatment units to the home market which may reduce concentrations of many trace contaminants. Various technologies, including activated carbon, reverse osmosis, distillation and ozonation, are incorporated in these units. Activated carbon is used in the majority of units since it removes taste- and odor-causing components and is relatively economical. Symons has summarized the literature in relation to the reported performance of activated carbon (7). This summary includes three pertinent points: 1) compounds producing taste and odor are removed by activated carbon; 2) adsorption of synthetic organic compounds is variable (some compounds, such as pesticides and polynuclear aromatics, are strongly adsorbed while others such as carbon tetrachloride are not); and 3) disinfection by-products (from drinking water), both precursors and trihalomethanes, are adsorbed at a much lower capacity than are pesticides and taste- and odor-causing compounds.

Review of data from this and other research projects indicated the need to develop basic data and information on the performance of small water treatment units with respect to organic compound removal and bacterial/endotoxin quality of treated water. Subsequently, an evaluation program was developed and is being implemented for the Environmental Protection Agency by Gulf South Research Institute. During Phase 1 of the project, seven models having a range of capacities, flow rates, and recommended plumbing configurations were evaluated at two stress levels. Experience gained during Phase 1 testing was used to plan a protocol for the operation and evaluation of units in the remaining two phases. During Phase 2, 25 additional units were evaluated using basically the same protocols. Phase 3 will include evaluation of noncarbon units, more detailed evaluations of selected carbon units, field studies of selected units in several other U.S. cities (Miami, Florida; Atlanta Georgia; Detroit, Michigan; and Pico Rivera, California), and stress studies on selected units involving additional organic chemical spikes and source waters.

This report includes the results of Phase 2 evaluations. To reduce the bulk of the report, most of the basic data and plots of results for individual units have been included in "Phase 2 Supplemental Data," which is available on request.

SECTION 2

EXECUTIVE SUMMARY

Gulf South Research Institute has evaluated 25 water-treatment units, containing activated carbon, designed for home use. The units were tested for removal capabilities with respect to broad-scale organic materials (nonpurgeable total organic carbon, NPTOC), carbon tetrachloride, and selected trihalomethanes (THM). The selected trihalomethanes were chloroform, bromodichloromethane, dibromochloromethane, and bromoform. Bacterial and endotoxin content was also evaluated in the study. The protocol for testing was developed jointly with EPA and was reviewed by a committee of the Water Quality Improvement Standards and Certification Council. Some of the unit manufacturers have not made explicit claims for organics removal, and only 10 have made claims for bacteriostatic effects; consequently, some units may have been tested beyond their claims in order to provide information for the guidance of consumers and government. Units were operated according to the manufacturer's instructions when they were reasonable and likely to be followed by consumers. The philosophy of the test program was to stress the units under conditions simulating home use. All units were challenged with ambient New Orleans tap water.

The twenty-five activated-carbon units in Phase 2 of this study were selected to reflect a variety of filter configurations including six faucet filters (five bypass and one nonbypass), two portable pour-through filters, four stationary filters, and thirteen line-bypass filters. Ten units incorporated silver-impregnated activated carbon, and fifteen units did not contain silver. In general, the filters contained various amounts of granular activated carbon (30 to 3402 g). They were installed to allow flow rates simulating flow from the home tap, and resulting contact periods were 0.2 to 180 sec. By comparison, large-scale, activated-carbon filters used in central water-treatment facilities are from 2 to 15 ft deep, and contact periods range from 5 to 30 min.

RESULTS

Organic Compound Removal

THM--

Small faucet and pour-through filters removed from 4 to 69 percent of the influent THM during the rated lifetime of units. Larger stationary and line-bypass filters removed greater percentages, ranging from 15 to 98 percent. Six line-bypass units (including one unit containing an experimental material) removed over 85 percent of influent THM. The extent of THM removal appears to be a function of several factors, including quantity of carbon relative to amount of water processed, type of carbon, contact time, and design features.

CCl_4--

Carbon tetrachloride was rarely detected (17 out of 227 analyses over an 8 month period) and, if present, was in concentrations ranging from 0.6 to 2.2 ppb. The existence of such small amounts of CCl_4 in tap water during

the period of unit testing did not justify the calculation of percent average reduction of CCl_4 for the test units. Therefore, CCl_4 concentrations were summed with THM concentrations when determining percent THM reduction.

NPTOC--

Percent removal of nonpurgeable total organic carbon was lower than percent removal of THM for all units except two faucet-mount units. Removal percentages ranged from 0 to 87 percent for line-bypass units, from 0 to 31 percent for faucet-mount units, from 7 to 11 percent for stationary units, and from 6 to 14 percent for pour-through units. Again, as a group, the larger filters exhibited higher percentage removals than smaller filters.

Microbiological Parameters

Standard Plate Count (SPC)--

The SPC results were divided into three populations: 1) test-unit effluent levels one or more log units less than control-loop levels (population B1); 2) test-unit effluent levels within ± one log unit of control-loop levels (population B2); and 3) test-unit effluent levels one or more log units greater than control-loop levels (population B3). All units had data sets in population B3, ranging from 13 to 73 percent of total data sets, whereas many units did not have data sets in population B1. In fact, data sets in population B1 ranged only from 0 to 21 percent of total data sets for respective units. The majority of units had their largest portion of data sets in population B2, ranging from 8 to 81 percent of total data sets for respective units. The pattern of data sets for individual units was variable, with reversals from populations B1 to B3 or vice versa occurring between consecutive sampling events. These SPC data indicated moderate and variable effects of activated carbon on bacterial levels in test-unit effluent waters as compared with New Orleans tap water sampled under similar conditions (control-loop). In tests for coliform bacteria, none were found in control-loop samples or test-unit effluents.

Endotoxin--

The endotoxin results were divided into three populations: 1) test-unit effluent levels less than one-half control-loop levels (population E1); 2) test-unit effluent levels within 1/2 and 2X control-loop levels (population E2); and 3) test-unit effluent levels greater than 2X control-loop levels (population E3). The endotoxin results are similar to SPC results. All test units had data sets in population E3, ranging from 7 to 65 percent of total data sets, while data sets in population E1 ranged from 0 to 40 percent of total data sets. The majority of test units had data sets in population E2 as the largest portion of respective sets, ranging from 20 to 93 percent of total data sets. Rapid shifts or reversals in endotoxin levels were often observed on consecutive sampling periods. Test-unit effluent endotoxin levels were comparable to levels found in 27 different public drinking water supplies utilizing activated carbon treatment (injection of these test waters had failed to demonstrate pyrogenic activity in any of 28 rabbits tested).

Statistical Analyses--

Silver effects--Effluents from silver-impregnated activated carbon units had silver levels within the Interim Primary Drinking Water maximum contaminant level (MCL) of 50 ppb (average levels ranged from 2-12 ppb).

Under the test conditions, the data sets for all three categories of SPC bacteria (B1, B2 and B3) and of endotoxin (E1, E2 and E3) were essentially equivalent for silver and non-silver units, showing no significant impact of the silver-impregnation.

Further, statistical methods (student t test) also indicated there was no significant difference between the respective SPC populations and endotoxin populations obtained from silver and non-silver units. Thus, it is concluded that silver-impregnated activated carbon units challenged with New Orleans tap water (pH 9.5) do not significantly reduce bacterial growth patterns.

SPC1 versus SPC2--SPC values obtained by incubating plates at 35°C for 48 hours (SPC1) have a linear correlation (correlation coefficient = 0.87) with plate counts obtained by incubating plates at room temperature (25°C) for 120 hr (SPC2).

SPC versus Endotoxin--A linear correlation was not observed between $\log_{10}$ of the SPC and endotoxin.

Test-Unit Effluents versus Control-Loop Samples--Out of eight SPC1 and SPC2 statistical analyses, six indicated significantly higher test-unit SPC effluent levels as compared to control-loop levels. Differences between SPC levels varied from 0.20 to 1.08 log units. The data also revealed that increasing degrees of stagnation (from running water to 5-day stagnation) result in higher SPC levels for both test-unit effluents and control-loop samples; in fact, SPC bacteria increased more rapidly in control-loop samples than in test-unit effluents. Endotoxin results were less clear-cut, with only two out of four statistical analyses showing significantly higher levels in test-unit effluents as compared to control-loop samples. Differences between respective endotoxin levels ranged from 0.7 to 1.4 ng/ml.

SECTION 3

EXPERIMENTAL PROCEDURES

TEST PROTOCOLS

Overview of Phase 2 Experiments

Twenty-five models of activated-carbon units for treatment of water in the home were evaluated during Phase 2. Each model was challenged with ambient New Orleans municipal drinking water from the GSRI laboratory during three duplicate test runs. Performance parameters monitored were nonpurgeable total organic carbon, carbon tetrachloride and trihalomethanes, standard plate count, endotoxin, silver, and free and total chlorine. Only the water samples from models incorporating silver in the carbon matrix were analyzed for silver. Other complementary data, including gallons of water processed, room and water temperature, time and date of sampling, iodine number of activated carbon, and coliform, were determined and recorded for each unit.

These procedures and parameters were designed to yield accurate, reliable data to evaluate the effectiveness of the units in reducing or removing carbon tetrachloride and trihalomethanes and nonpurgeable total organic carbon, and to provide important information on bacterial and endotoxin content. The protocols were developed by incorporating input from EPA, private manufacturers, and industry.

Performance Testing/Sampling Schedule

Each unit was installed on the test manifold and plumbed according to the manufacturer's recommendations. Suggested startup procedures were completed before initiation of each run. The flow rate of most units was not regulated except by restrictions in the filter device and associated hardware, primarily the faucet and line-tapping valves. The test manifold was designed with oversized tubing so that the manifold itself was not flow restricting. Test flow rates were determined by evaluating the flow through the plumbing train (including an appropriate faucet and tapping valves) with the manifold's orifice monitor/controller fully open. Pressure was held constant at 40 psi. The faucet was then removed from the plumbing train and the unit installed. If the flow rate exceeded that originally allowed by the manufacturer-supplied hardware, the controller was set to the flow rate determined in the original 40 psi test. Through this initial adjustment, the normal maximum flow rate was applied to each model during each run. The same procedure was followed for all units operating in the pressurized mode. Flow through the pour-through models was set to the manufacturer's recommended values by adjustment of the orifice.

The schedule for sampling events and run duration was based on individual unit capacity and flow rate. For units where flow rate and capacity (gallonage) were not available, values of similar units with equivalent amounts of carbon were employed. This procedure was used to

establish the total number of gallons to be processed by each unit per day. Sampling events were scheduled at or near predetermined gallonage values for each model. Figure 1 depicts a general usage profile showing the main sampling events. For the triplicate runs, samples were taken at least five times during the life of the test units. These five events corresponded to approximately 0, 25, 50, 75 and 100 percent of the unit life expectancy.

A typical 24-hr day sampling schedule is depicted in Figure 2. Each day included an 8-hr stagnation which simulated overnight non-usage time. The units were then intermittently run for 16 hr, held stagnant for 8 hr, and the cycle repeated. Most samples for bacterial/endotoxin assay were collected immediately after the overnight stagnation periods (i.e., "first water samples"). The carbon tetrachloride, THM, NPTOC, silver, and chlorine samples were collected approximately 6 hr after the start of the test day and 1 min after the downstream holdup volume of the unit had been wasted. This collection procedure ensured collection of a dynamic sample rather than a sample which had extended contact time with the adsorbent material. Influent or control-loop effluent and test-unit effluent water samples were collected for comparison and analysis of the various performance parameters.

The first of the triplicate tests was a "range-finding run" during which the total rated gallonage was confirmed. The run was designated to be as short as possible, but the total run was not to be less than five days. Only carbon tetrachloride, THM, NPTOC, and chlorine samples were collected and analyzed. The maximum flow time available to any unit was set by the timer cam control system to approximately 466 min per day, providing approximately 29 min/hr of running time for each of the 16 hourly cycles per day. For a unit with a flow rate of 0.8 gal/min, the water processed per day is 0.8 gal/min x 29 min/cycle x 16 cycle/day = 371 gal/day.

During the second and third runs on each model, the target duty cycle was no more than 10 percent "on" for each hour during the 16-hr working day. Therefore, for each of the 16 hr of manifold operation each day, the running time was limited to approximately 6 min per hourly cycle, or 96 min a day (i.e., 96 min x 0.8 gal min = 76.8 gal/day). The expanded list of performance parameters in Figure 1 was monitored during the second and third runs. In addition to the "first water" samples collected for SPC and endotoxin analysis, several "running water" samples were collected and analyzed.

The units were run until the manufacturer's rated gallonage had been processed or until the unit failed by premature plugging. While early protocols included a chemical failure option for test run termination (10 percent or less removal), this criterion was never implemented. A bacterial sample was collected five days after the termination of a run to determine what effect extended dormancy had upon effluent water quality. When the second and third trial runs were completed, the flow through the units was stopped and the units were held under line pressure, if applicable, for five days; then, the units were turned on long enough to collect the last SPC/endotoxin and coliform samples.

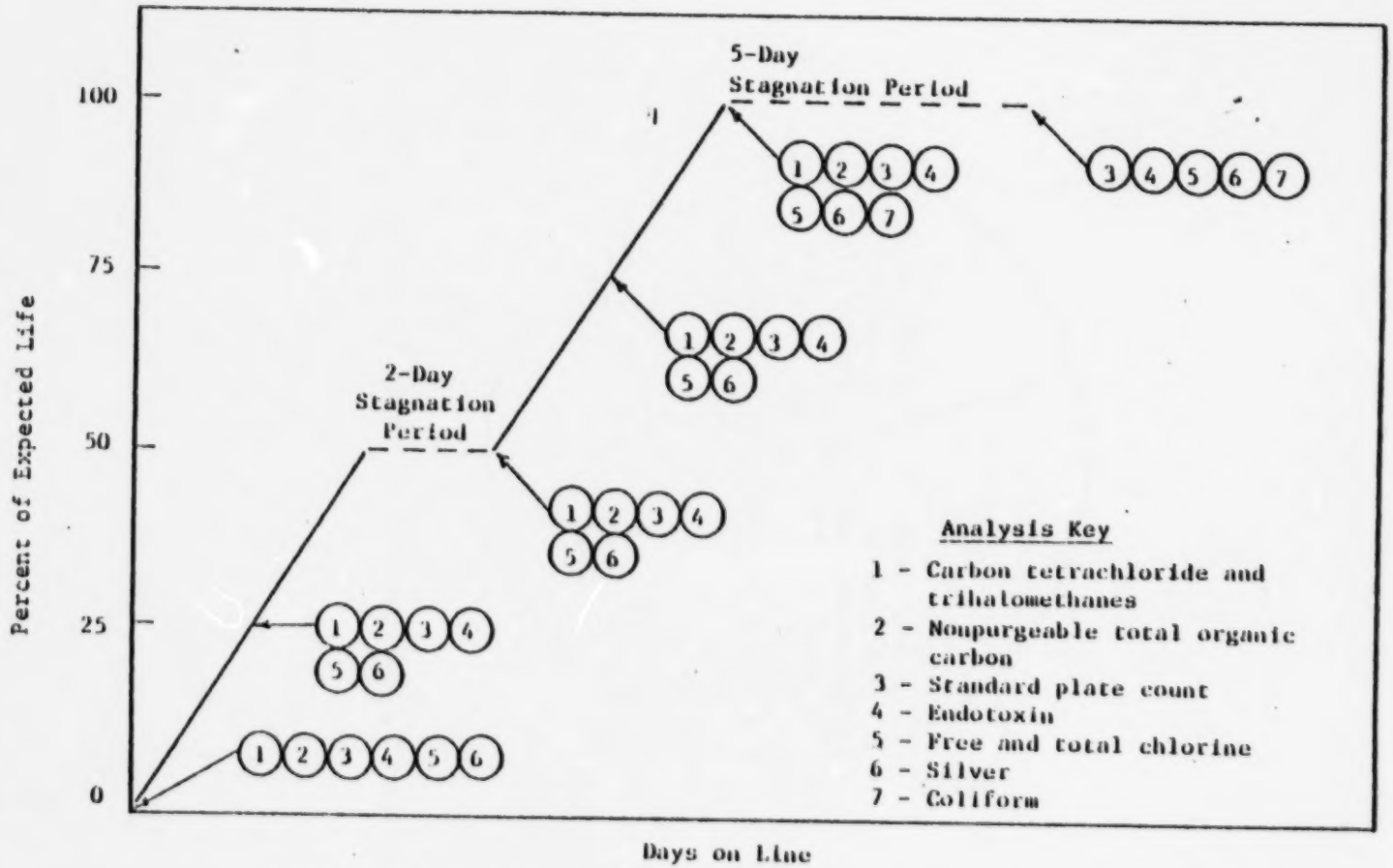


Figure 1. General usage profile indicating target sampling events.

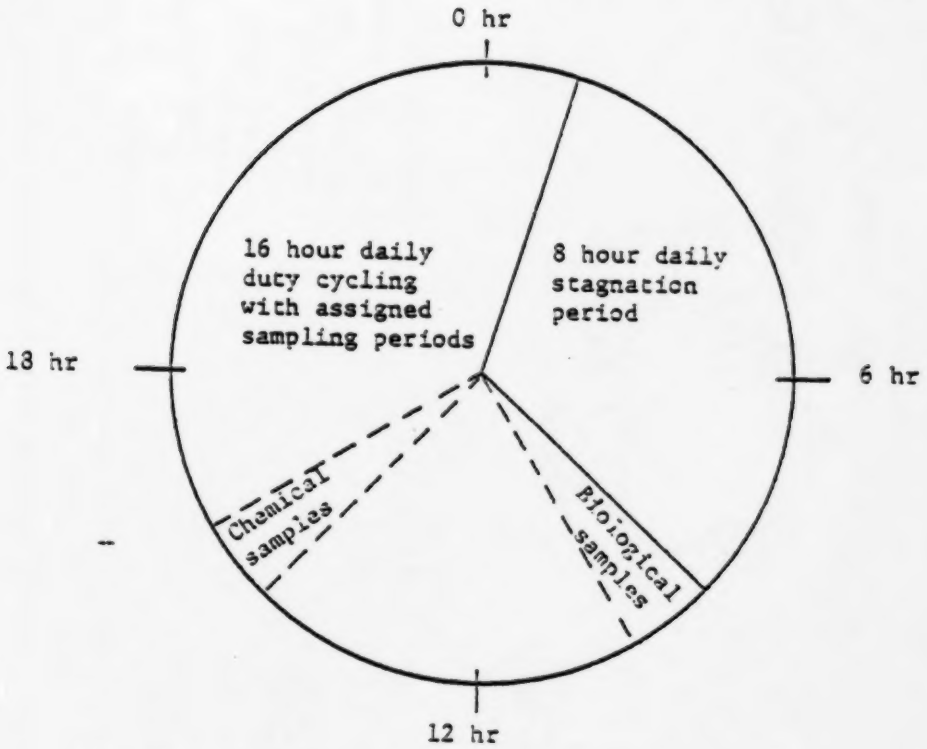


Figure 2. Routine daily schedule for all test models.

Physical Examinations

The water-treatment units were examined externally and internally with the following objectives:

1. To determine the basic functional category of the unit.
2. To find any special feature which might enhance functionality, versatility, or overall desirability.
3. To describe internal design features, filtering medium(s), flow regulators, or other significant internal characteristics.
4. To determine the type, quantity, and particle range of the filtering media.
5. To establish recommended operating conditions by examining and recording all pertinent data from the nameplate and enclosed literature.

One of each test model was dissected before testing to examine the internal construction, filter medium(s), and their placement within the unit. Samples of the carbon were collected aseptically for evaluation of bacterial and endotoxin content and determination of iodine numbers (8). Filter media were classified by type (sand, carbon, zeolite, etc.) and gross shape (powder, granular, or pellet). The total weight of carbon was used to estimate total unit capacity on units not rated for this parameter. The apparent internal flow design of the unit was recorded.

SELECTION OF UNITS

The water-treatment devices were chosen on the basis of the following criteria:

1. Size - models were selected to cover a range of sizes but limited to devices small enough to be conveniently utilized in most domestic kitchens.
2. Installation configuration - models selected for Phase 2 study were grouped into one of four categories depending upon intended plumbing configuration or principal treatment process. The categories were pour-through, faucet-mount, stationary, and line-bypass. Within each category, study models were selected to cover range sizes, capacities, filtration media, etc.
3. Claims - some selections were based upon special claims or unique features (e.g., chloroform removal, automatic flow control, bacteriostatic capabilities). Specific claims for removal of organics received special attention since these claims could be validated through the test protocol.
4. Availability - It was decided to test only commercially available units. However, custom-made units by Rohm & Haas were tested to investigate the properties of an experimental material possessing unique absorption characterisics - Ambersorb XE-340. Consideration was given to the marketing thrust of selected filters since product visibility has a direct impact on the availability of the device to the consumer.

Phase 2 - Study Unit List

1. Faucet-mount (line-bypass)
   a. Aquaguard, Model AGT-31, cartridge T-3XL
   b. Concept Bacteriostatic Home Water Filter*
   c. Filter Fresh, Model FF-1
   d. Hurley Town & Country
   e. Water Washer, Countertop Model 1000*
   f. Wunderbar Portable Water Cleaner - Filter (no line bypass)
2. Pour-through
   a. Filbrook Pour-Thru Activated Carbon
   b. Puriton Bacteriostatic Drinking Water Treatment Unit*
3. Stationary
   a. AMF-Cuno, Housing 1M Cartridge AP-117
   b. Filterite, Model 1PC, Cartridge 1C-9
   c. Fulflo Water Filter, Model WC-10
   d. Keystone, Model 3121, Housing with Model 310 Cartridge
4. Line-bypass
   a. Argenion Bacteriostatic Water Treatment Unit, Model 1*
   b. Aquacell Bacteriostatic Water Treatment Unit*
   c. Aqualux Water Processor, Model CB-2*
   d. Continental Water Filter, Model 350
   e. Culligan Super Guard, Model SG-2
   f. Everpure, Model QC4-THM
   g. Mariner Renaturalizer Water Unit*
   h. Polarisdynamic Water Unit*
   i. Purogen Water Detoxifier
   j. Rohm & Haas, Ambersorb XE-340**
   k. Seagull IV
   l. Ultrapure Bacteriostatic Water Processor*
   m. Waterco, Model AS-5*

*Incorporates silver-impregnated carbon
**Not commercially available.

METHOD OF ANALYSIS

Carbon Tetrachloride and Trihalomethane Analysis

Sampling--

Crimp-top serum bottles with Teflon-lined septa were used to collect the samples. Prior to sampling, the bottles were cleaned using the following procedure:

--Wash in a hot soap and water solution
--Rinse in tap water
--Rinse in Chromerge
--Rinse thoroughly in deionized water
--Rinse thoroughly in distilled water
--Rinse in methanol
--Drain dry
--Heat at 400°C for at least 1 hr
--Cool to room temperature

--Add 1 ml of 0.25 percent sodium sulfite per 100 ml sample
--Cap using Teflon-lined septum and crimp top, making sure the Teflon lining faces the sample.

When samples were collected, the crimp top was removed and the bottle filled to overflowing. Care was taken in resealing the sample bottle to avoid inclusion of air which could result in the loss of volatile organic compounds. The sodium sulfite solution added to each sample is generally accepted as adequate to quench the haloform reaction which results from the chlorination of drinking water. Samples were refrigerated at 4°C until analyzed.

Analysis--

The analysis of water samples was performed using liquid-liquid extraction techniques followed by separation and determination of the five compounds of interest by gas chromatography (GC) with a ^{63}Ni electron-capture (EC) detector (10-12). This method has produced results which correlate well with those generated by purge-and-trap procedures (12,13).

Reagent-grade methylcyclohexane (MCH) was used as the solvent. The MCH was purified by distillation and, if necessary, by passing it through a basic alumina column. A 5-ml aliquot of sample was extracted by shaking with 1 ml of purified MCH. The layers were allowed to separate, and a 3-µl portion of the organic layer was injected into the GC. Chromatographic conditions and a typical GC trace for this analysis are shown in Figure 3. Qualitative identification was based on matching the retention times of peaks in the sample chromatogram with those in the chromatogram of a standard mixture containing the five compounds of interest: chloroform, carbon tetrachloride, bromodichloromethane, dibromochloromethane, and bromoform. Confirmation of compound identity (no interfering compounds were observed in drinking-water samples) was possible by reanalyzing any sample in question under different conditions of liquid phase, solid support (GP 20 percent SP-2100/0.1 percent Carbowax 1500 on 100/120 Supelcoport), temperature, and flow rate (Table 1). The quantification technique employed was the external-standard method, and all calculations were based on integrated peak areas.

Nonpurgeable Total Organic Carbon Analysis

Sampling--

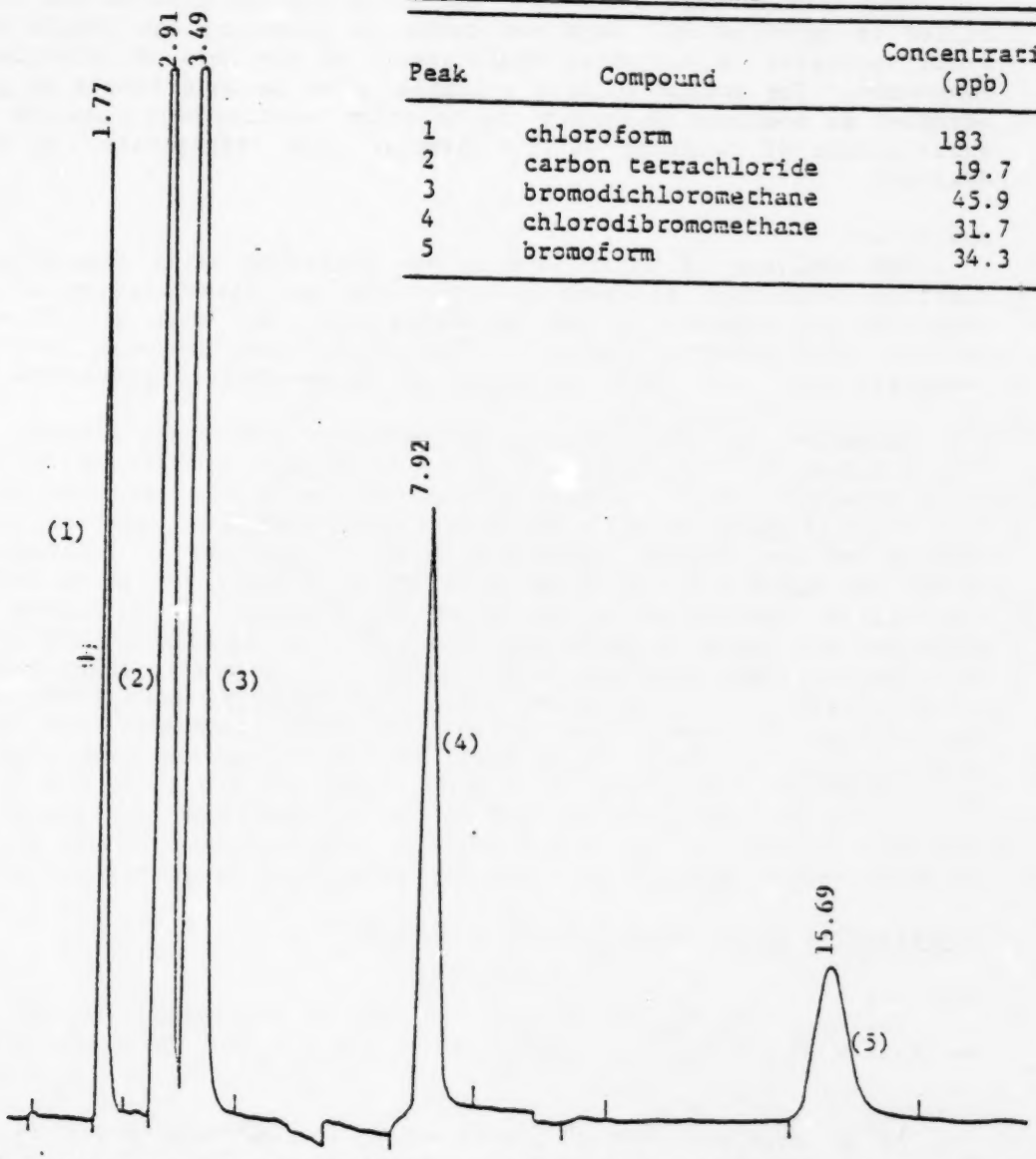
Cleaning and sampling techniques used in collecting samples for NPTOC analysis were identical to those used in the CCl_4 and THM analysis procedure.

Analysis--

NPTOC analyses were performed using the Dohrmann model 54 analyzer. Using the procedure outlined by the manufacturer (14), 10 ml of sample was presented to the instrument, acidified, purged for inorganic carbon, and oxidized using an ultraviolet light catalyzed system. The carbon dioxide produced was converted to methane, and the methane was detected and quantified using a flame-ionization detector.

LEGEND

Peak	Compound	Concentration (ppb)
1	chloroform	183
2	carbon tetrachloride	19.7
3	bromodichloromethane	45.9
4	chlorodibromomethane	31.7
5	bromoform	34.3



Gas chromatographic conditions: 6 ft x 1/8 inch i.d. glass column packed with 10% Squalane on Chromosorb W, AW 80/100 mesh; carrier gas 5% methane, 95 argon; flow rate 20 ml/min; injector temperature 150°C; column temperature 67°C (isothermal); Ni^{63} electron capture detector temperature 300°C.

Figure 3. Representative chromatogram of a check standard.

TABLE 1. CHROMATOGRAPHIC CONDITIONS FOR CCl_4 AND THM

Parameter	General	Confirmatory
Column	6 ft x 2 mm i.d. 10% Squalane AW Chromosorb W 80/100 mesh	6 ft x 2 mm i.d. GP-2100/0.1% Carbowax 1500 on Supelcoport 100/120 mesh
Injection temperature	150°C	150°C
Oven temperature	67°C	80°C
Detector temperature	300°C	300°C
Flow rate	20 ml/min	30 ml/min
Injection volume	3 µl	3 µl

Inorganic Analyses (Silver)

Sampling--

Glass bottles were washed in hot water and detergent, rinsed well with tap and deionized water, cleaned with 1:1 nitric acid:water, rinsed thoroughly with deionized water, and drained dry. Samples for silver analysis were preserved upon collection with nitric acid (to lower the pH to less than 2) and stored at 4°C.

Analysis--

Influent and effluent samples were prepared for silver analysis by digesting 200 ml of sample with 3 ml of concentrated nitric acid and 5 ml of 30 percent hydrogen peroxide. The samples were covered with a watch glass and heated at 95°C until the volume was reduced by evaporation to less than 50 ml. The digested sample was cooled and diluted to 50 ml with distilled, deionized water. The digested, concentrated samples were analyzed for silver using a Perkin-Elmer 303 or 306 atomic absorption spectrophotometer (AAS) equipped with a heated graphite atomizer (HGA 200 or HGA 2100), deuterium background correction and a strip-chart recorder. A series of standards was prepared and analyzed with each set of samples. The height of the absorbance peak of each standard was measured and correlated with the respective concentration to produce a calibration plot. Silver was quantified by comparison of sample absorbance peak height with the standard calibration plot.

Arsenic, barium, cadmium, chromium, lead, and selenium were determined in a similar manner on New Orleans tap water by flameless atomic absorption using a Perkin-Elmer 303 AAS equipped with a HGA 2000, deuterium background correction, and a chart recorder. Samples were prepared for analysis by digesting 100 ml of sample with 3 ml concentrated nitric acid and 5 ml 30 percent hydrogen peroxide (15). The following inorganic parameters were determined by using techniques cited in the Manual of Methods for Chemical Analysis of Water and Wastewater (16). Fluoride was measured using an Orion ion activity electrode. The cadmium-reduction method was used to determine nitrate nitrogen. Total dissolved residue was determined gravimetrically. A nephelometer was used for determination of turbidity. Conductivity and pH were determined with a YSI conductivity bridge and an Orion digital pH meter.

Chlorine Analysis

Sampling--

Samples for chlorine analysis were collected in clean 250-ml Ehrlenmeyer flasks with glass stoppers and titrated within 60 min.

Analysis--

Concentrations of free and residual chlorine in influent and effluent water samples were determined using a titrimetric method (8). Free chlorine was determined by transferring 100 ml of sample, 5 ml of phosphate buffer, and 5 ml of DPD indicator (N,N-diethyl-P-phenylenediamine) to a 250 ml flask and titrating immediately with a standard FAS titrant (ferrous ammonium sulfate) until the red solution became colorless. Residual chlorine was determined by adding ≅1 g of KI to 100 ml of sample, waiting 2 min for

complete color formation, and titrating as for free chlorine. Because of relatively low concentrations found for free and residual chlorine, the standard FAS titrant (1 ml FAS = 1 ml/l chlorine) was diluted 1:10 for increased accuracy.

Microbiological Analysis

Sampling--

All sample bottles and glassware used for microbiological analyses were washed with detergent and hot water, rinsed with hot tap water, and thoroughly rinsed with distilled water. The glassware was sterilized by heating at 170°C for 60 min. A sterile-filtered solution of 7.3 percent sodium thiosulfate and 5 percent sodium thioglycolate was added to each sample upon collection at the rate of 1 ml per 100 ml sample. The thiosulfate and thioglycolate neutralize any chlorine or silver present in the sample and thereby prevent bacterial kill after sample collection. Samples were cooled to 4°C immediately and stored until analysis. Standard plate count and coliform determinations were performed according to standard procedures (9).

Analysis--

Standard Plate Count--A standard plate count was performed within 30 hr of sample collection according to standard procedures (9). Dehydrated agar was reconstituted and sterilized according to the manufacturer's instructions. The agar was melted and tempered in a 44-46°C water bath. Each water sample was divided into two portions (sets). Each portion was diluted with sterile water and each set plated in triplicate at the following concentrations: influent 10^{0}, 10^{-1}, 10^{-2}; effluent 10^{-1}, 10^{-2}, 10^{-3}; and carbon washings 10^{0}, 10^{-1}, 10^{-2}. One set of plates at each concentration was incubated at 35° ± 0.5°C for 48 ± 3 hr while the other set of plates was incubated at room temperature (≅25.0°C) for 120 ± 3 hr. The colonies growing on each plate were counted using a Quebec colony counter. All samples (each set) were analyzed in triplicate.

Endotoxin Assay--The endotoxin assay was conducted using the Worthington *Limulus* amebocyte lysate (LAL) Pyrostat test kit, a turbidimetric modification of the *Limulus* amebocyte lysate gel test for detecting pyrogen (17-20). Each sample was diluted 1:10 and 1:25 to insure that the endotoxin concentration of the sample fell within the range of the standard curve. A 0.1 ml aliquot of diluted sample or reference endotoxin standard was added to a chilled test tube containing 1.0 ml LAL reagent. The contents of the tube were thoroughly but gently mixed, and the tube was placed into a 37°C water bath to incubate for 60 ± 1 min. The contents of the tube were transferred to a cuvette, and the optical density measured with a Varian Techtron UV-Vis spectrometer. A four-point standard curve was constructed by using the concentration and optical density of the reference endotoxin standards. The optical density of each sample was compared to the standard curve to determine concentration of endotoxin in the sample.

Standard Total Coliform--The membrane filter procedure for determination of standard total coliform was selected over the multiple-tube fermentation technique because the former permits examination of large volumes of water, generates highly reproducible data, and tests a large number of samples with ease. One hundred milliliters of sample is passed through a 0.45-μ pore diameter membrane filter. The filter is placed on a pad sat-

urated with M Endo medium and is incubated for 24 ± 2 hr at 35° ± 0.5°C. Colonies having a pink to dark-red color with a metallic sheen are assumed to be coliforms and are counted with the aid of a binocular wide-field dissecting microscope at 10 to 15X.

QUALITY ASSURANCE/QUALITY CONTROL PROTOCOLS

CCl_4 and THM Analysis

A rigorous quality-control program was followed in conjunction with these analyses. Before Phase 1 of this program, a nine-point calibration curve was constructed for each compound to establish detection limits and linearity ranges. Performance samples were supplied to GSRI by the Environmental Monitoring and Support Laboratory of EPA for verification of the analytical procedure. A satisfactory rating was received. The following quality-control samples were run each time the samples were analyzed during Phase 2:

- --solvent blank - aliquot of solvent which was used to extract that day's samples
- --method blank - extract of water which was used to prepare standard
- --low standard - standard in which the concentration of each compound was higher than at the midpoint of the calibration curve
- --check standard - standard in which the concentration of each compound was approximately the concentration expected in the samples
- --duplicates - extracts from two samples collected sequentially from the same sampling point
- --spikes - extracts from two samples collected sequentially from the same sampling point. One of these samples was fortified with a mixture of the compounds of interest at known concentrations.

Analysis of solvent and method blanks provided a check on the purity of the materials used in the procedure. If any amount of the five halomethane compounds was detected in these samples, that material, either solvent or water, was purified again and reanalyzed before it was used. Analysis of the low, high, and check standards monitored the performance of the GC on a day-to-day basis. If values obtained from analysis of these quality-control samples ranged outside the limits of precision, the nine-point calibration curve was reconstructed and/or a thorough check of the instrument parameters, column conditions, and detector response was made.

The precision of the procedure was established by the analysis of duplicates. Precision was quantified according the the equation

$$R_c = 3.27C \frac{\Sigma R_i}{\Sigma X_i} \qquad (1)$$

where

R_c = critical difference
X_i = average value obtained for duplicate analyses
R_i = difference between the values obtained for duplicate analyses.

Qualitatively, the smaller the R_c value, the better the precision of the analysis. Quality-control charts were generated from these data and updated every day the analyses were performed.

Accuracy of the analyses was monitored by comparing the value obtained for the check standard (O_i) with the true value (T_i).

$$P_i = 100(O_i - X_i)/T_i \qquad (2)$$

where

P_i = percent recovery (accuracy)
O_i = observed value
T_i = true value
X_i = dilution factor (if significant)

The recovery efficiency of the analysis was determined by analyzing spiked samples and comparing the difference in the values obtained for the spiked and unspiked samples with the level at which the sample was spiked (essentially equation 2). If the halomethane concentration in the sample was expected to fall in the lower half of the calibration curve, the sample was spiked at a level approximately equal to the concentration of the compounds already present. If the sample concentration was anticipated to be above that of the midway point of the calibration curve, the spike was approximately half of the value expected in the sample. Quality-assurance data are presented in detail in "Phase 2 Supplemental Data," Tables S1 through S3.

NPTOC Analysis

The quality-control program associated with the NPTOC analyses was similar to that described for CCl_4 and THM analyses. Because the method of analysis for NPTOC is very reliable, a reduced schedule for the analysis of QA/QC samples was employed as follows:

Monday - water blank, method blank, low standard, high standard, check standard, duplicates, and spikes
Tuesday and Thursday - water blank, method blank, low standard, check standard, and duplicates
Wednesday and Friday - water blank, method blank, high standard, check standard, and spikes.

Precision, accuracy, and recovery data for NPTOC analyses are included in the supplementary data, Tables S4 through S6.

Silver Analysis

The quality-control program for silver analyses was conducted concurrently with individual silver analyses. QA/QC samples representing 10 percent of the total number of samples for silver analysis were analyzed. These QA/QC samples included duplicate samples, spiked samples, and quality-control standards. Precision, accuracy, and recovery data for silver analysis are presented in the supplementary data, Tables S7 through S9.

Microbiological Analysis

Sterility of medium, dilution water, glassware, and membrane filters was verified by preparing blank control plates with each set of samples examined by the SPC or LAL (endotoxin) procedures. Standard plate counts were plated in triplicate, and endotoxin determinations were calculated at two dilutions.

SECTION 4

RESULTS AND DISCUSSION

GENERAL OBSERVATIONS

Test Water Quality

The experimental program was designed to simulate variable stress conditions activated-carbon units might experience in home use. Tap water drawn from the New Orleans municipal water supply was employed as the basic inlet water. The Mississippi River is the raw water source for which classical treatments of permanganate oxidation (as needed), flocculation, lime softening, and disinfection at the water-treatment plant are employed.

Gulf South Research Institute is approximately 10 miles from the treatment plant. The Institute's water is obtained through a feeder line which connects approximately 1 mile from the site with one of the distribution loops of the city. Sharing the feeder line with GSRI are three light industries, one recreational park, and three military reserve centers. The average water consumption in the laboratory during the test period was 308,300 gal per month (ranging from 197,900 to 460,300 gal per month). Although the water-usage pattern fluctuated, the volume of water flowing through the building was adequate to maintain a representative sample. It is estimated that the water at the GSRI point of use has had approximately a 48-hr residence in the distribution system.

There are several features of this tap water which may distinguish it from some other sources. The pH of the water is basic; typical values range between 9 and 10. Total nonpurgeable organic carbon concentrations are not exceptionally high (range between 1.7 and 3.5 ppm); however, the mixture of organic compounds which comprise this total may be one of the most complex groups of chemicals found in domestic drinking water supplies. The Mississippi River contains pollutants from all surface water drained from the mid-continental United States. This water contains humic, agricultural, and other wastes. Several cities dispose sewage waste through the Mississippi River, and the river has a large number of chemical and petrochemical industries along its banks. Table S10 reports typical values for the various water-quality parameters of ambient New Orleans drinking water used during the test period.

Secondary parameters which contribute to a better understanding of test results were monitored daily. These parameters included room and water temperature and free and residual chlorine concentrations. The room temperature fluctuated around 24°C. Larger variations are found in fall and winter months when weather is unpredictable. GSRI conserves energy by controlling the heating and cooling systems with a 24-hr clock so that when the building is not in use, the air conditioning system is off. Many home users exercise this same conservation practice; therefore, GSRI's air-conditioning pattern is consistent with home exposure. In the summer months, room temperatures increased approximately 5°C during the off-cycle

period; this pattern moderated to a lowering of 2-3°C in winter months. The average water temperature was approximately 2°C higher than room temperature in summer and dropped to around 6°C lower than room temperature in winter. These seasonal changes in temperature influence trihalomethane influent concentrations, influent and control-loop bacterial water quality, and, possibly, free-chlorine concentrations (which influence bacterial water quality).

Table S11 reports the daily influent water concentration of CCl_4, THM, and NPTOC during testing period. In addition, Table S87 lists the bacterial, physical, and chemical properties of control-loop effluent and/or influent water. Figures S1 and S2 illustrate room and water temperature and their typical 24-hr exposure patterns. Figure S3 correlates SPC and free chlorine concentrations. Figures S4 and S5 show the daily control-loop endotoxin concentrations and influent THM and NPTOC levels.

Physical Description of Home Treatment Units

A physical description of the 25 units tested during Phase 2 of this project is presented in Tables 2 and 3. Four types of units were tested: 1) line-bypass, 2) faucet-mount, 3) stationary, and 4) pour-through. Each unit had a rated capacity (gallons/liters) provided by the manufacturer or estimated. Estimated capacities were determined by comparison of the amount of activated carbon in similar units. Capacity ratings, which are dependent on amount and type of carbon, ranged from 40 to 4000 gal. The amount of carbon in the units varied from 30 to 3402 g. The majority of units contained granular activated carbon. One experimental unit contained 2700 g of Ambersorb XE-340 resin (carbonaceous adsorbent), while other units incorporated various types of carbon-impregnated pads or sheets or powdered carbon.

The iodine number and amount of activated carbon, test flow rates, and design features are factors which determine the adsorption capacity of each unit. All units tested have very short empty bed contact times; the longest is 3 min. This empty bed contact time differs significantly from the 5- to 30-min contact times used in water-treatment plants (1).

REMOVAL OF ORGANIC CONTAMINANTS BY TREATMENT UNITS USING ACTIVATED CARBON

Organic contaminants have been divided into five classes in the "Interim Treatment Guide for Controlling Organic Contaminants in Drinking Water Using Granular Activated Carbon" (7):

Class I Organic compounds that produce taste and odor.
Class II Synthetic organic compounds that are present in source wastes from upstream.
Class III Organic chemicals (precursors) that react with disinfectants to produce "disinfection by-products."
Class IV Organic chemicals that are the "disinfection by-products."
Class V Natural organic compounds.

The regulations for control of organic contaminants in drinking water (21) specify a maximum contaminant level of 0.1 mg/l (100 ppb) for trihalomethanes. Activated carbon has been shown to have various levels of effectiveness in removing organic compounds which produce taste and odor and/or are disinfectant by-products or synthetic organic compounds (4-7). Activated

TABLE 2. PHYSICAL DESCRIPTION OF LINE-BYPASS CARBON MODELS TESTED

Unit	Rated capacity (gallons/liters)	Approximate volume of carbon (cm^3)	Carbon weight (g)	Iodine number	Test flow rate (gpm/lpm)
Argenion Bacteriostatic	2000/7571	285	146[a]	960	0.6/2.1
Aquacell Bacteriostatic	2000/7571	663	417[a]	867	0.9/3.2
Aqualux, Model CB-2	2000/7571	1760	1150[a]	966	0.8/3.0
Continental, Model 350	720/2726	7079	3402	960	0.6/2.3
Culligan, Model SG-2	4000/15142	2470	1708	980	1.0/3.8
Everpure, Model QC4-THM	1000/3785	1650	765	1223[b] 798[c]	0.6/2.3
Mariner Renaturalizer	3000/11356	1100	560[a]	1297	0.6/2.1
Polarisdynamic	2500/9464	930	527[a]	984	0.6/2.1
Purogen	2500/9464	852	859	650	1.2/4.4
Rohm & Haas, Ambersorb XE-340	3500/13249	2700	2353	570	0.9/3.2
Seagull IV	1600/6057	739[f]	300	434	0.8/3.0
Ultrapure Bacteriostatic	3000/11356	1400	1103[a]	771	0.8/3.0
Waterco, Model AS-5	3000/11356	755	495[a]	748[d] 828[e]	2.4/9.0

[a] impregnated with silver

[b] from cartridge #1 QC4-THM

[c] from cartridge #2 QC4-THM (includes binder and powdered carbon)

[d] carbon from upper level of filter

[e] carbon from lower level of filter

[f] block of carbon and binder

TABLE 3. PHYSICAL DESCRIPTION OF FAUCET-MOUNT, STATIONARY AND POUR-THROUGH CARBON MODELS TESTED

Unit	Rated capacity (gallons/liters)	Approximate volume of carbon (cm^3)	Carbon weight (g)	Iodine number	Test flow rate (gpm/lpm)
Faucet-mount--					
Aquaguard, Model AGT-31	500/1893	45[b]	51[a]	1275	0.2/0.8
Concept Bacteriostatic	40/151	11[b]	--[a]	--	0.1/0.4
Filter Fresh, Model FF-1	1200/4542	200	59	750	0.7/2.5
Hurley Town and Country	4000/15142	1765	895	913	0.8/2.9
Water Washer, Model 1000	1000/3785	310	70[a]	845	0.5/1.7
Wunderbar	200/757	6[b]	--	--	0.1/0.4
Stationary--					
AMF-Cuno, Model 1M	3000/11356	625[b]	395	870	2.6/9.7
Filterite, Model IPC	3000/11356	214[b]	--	--	2.9/11.0
Fulflo, Model WC-10	3000/11356	410[b]	208	1094	2.5/9.3
Keystone, Model 3121	3000/11356	354[b]	--	--	2.4/9.1
Pour-through					
Filbrook	1000/3785	146	97	788	0.04/0.2
Puriton Bacteriostatic	1000/3785	47	30[a]	1051	0.04/0.2

[a] Impregnated with silver
[b] Volume of pad or filter sheet (carbon impregnated)

carbon is produced from several sources. Properties of the carbon are dependent on source and the method of preparation; surface area is one of the most important physical properties of activated carbon. For specific application, the surface area available for adsorption depends upon the molecular size of the absorbate and the pore diameter of the activated carbon. The rate of removal is related to the surface area and to diffusion of the compounds in the liquid phase. Adsorption of an organic chemical on activated carbon is dependent on a variety of physical characteristics, including polarity, molecular size, water solubility, concentration of the compound in water, and pH of the source water. As previously noted, unit design features may also influence the effectiveness of compound adsorption on activated carbon.

Trihalomethane Removal

The summary performance of each home treatment model is reported in Tables 4 and 5 and Figures 4 through 7. The data indicate that the four basic configurations of filter models vary considerably (4-98 percent) in their ability to remove THM. Efforts to compare models with one another may result in biased interpretations unless the various experimental and individual unit parameters, such as design features, capacity, flow rate, and challenge water THM levels, are considered. The summary tables and figures are organized according to type of model since units within each category are designed to operate generally in the same manner.

Unit effectiveness in removing THM was determined by plotting the percent reduction of THM versus gallons processed for each of three trial runs. The averages of the three plots appear in Figures 4 through 7. Percent THM reduction was calculated by dividing the area under the average curve with the total area of the plot (gallonage x 100 percent). An additional criterion used to evaluate the effectiveness of THM removal is the amount of THM (g) removed (average influent load x unit rated volume capacity x percent reduction = amount removed). The amount of THM removed is determined in part by the average influent concentration, which varied over the duration of Phase II from 110 to 239 ppb. However, spike test runs in Phase 1 indicated that this variability of influent THM levels probably does not affect a unit's performance as much as the design features, capacity, and type and amount of activated carbon employed in respective units. In addition, if comparisons between types of units are made, amount as well as percent reduction of THM should be considered.

The summary data of THM removal indicate that line-bypass units generally are more effective in removing THM from New Orleans tap water than are stationary, faucet-mount, and/or pour-through units. Line-bypass units removed from 23 to 98 percent THM, whereas stationary units removed 15 to 41 percent; faucet-mount units, 4 to 69 percent; and pour-though units, 21 and 40 percent. A plausible explanation of these results is that line-bypass units generally contain more activated carbon and have larger rated capacities than the other three types of units. It must also be noted that some of the test units have not been designed to remove THM but have been designed to remove only taste and odor from water.

Chloroform was the predominant THM in New Orleans tap water. Carbon tetrachloride was rarely detected (17 out of 227 analyses over an 8 month period) and, if present, was in concentrations ranging from 0.6 to 2.2 ppb).

TABLE 4. SUMMARY PERFORMANCE: TRIHALOMETHANE REMOVAL DURING RATED LIFETIME FOR LINE-BYPASS UNITS

Unit	Rated capacity (gallons/liters)	Average influent concentration (ppb)	Total influent load (g)	Amount removed by activated carbon (g)	Amount removed by activated carbon (%)
Argenion	2000/7571	163	1.24	0.29	23
Aquacell	2000/7571	203	1.54	1.32	86
Aqualux	2000/7571	167	1.26	1.23	98
Continental	720/2725	203	0.55	0.54	99
Culligan	4000/15142	203	3.08	2.74	89
Everpure	1000/3785	174	0.66	0.65	99
Mariner	3000/11356	220	2.49	1.17	47
Polarisdynamic	2500/9464	143	1.35	0.82	61
Purogen	2500/9464	183	1.74	0.66	38
Rohm & Haas*	3500/13249	188	2.49	2.32	93
Seagull IV	1600/6057	226	1.37	0.96	70
Ultrapure	3000/11356	222	2.52	1.01	40
Waterco	3000/11356	193	2.20	0.55	25

*Test unit is not commercially available; unit contains Ambersorb XE-340, an experimental absorbent material.

TABLE 5. SUMMARY PERFORMANCE: TRIHALOMETHANE REMOVAL DURING RATED LIFETIME FOR FAUCET-MOUNT, STATIONARY AND POUR-THROUGH UNITS

Unit	Rated capacity (gallons/liters)	Average influent concentration (ppb)	Total influent load (g)	Amount removed by activated carbon (g)	Amount removed by activated carbon (%)
Faucet mount					
Aquaguard	500/1893	195	0.37	0.16	43
Concept	40/151	194	0.03	0.005	16
Filter Fresh	1200/4542	239	1.08	0.06	6
Hurley T & C	4000/15142	130	1.97	1.36	69
Water Washer	1000/3785	110	0.42	0.17	41
Wunderbar	200/757	220	0.17	0.007	4
Pour-through					
Filbrook	1000/3785	225	0.85	0.34	40
Puriton	1000/3785	206	0.78	0.16	21
Stationary					
AMF-Cuno	3000/11356	217	2.46	0.84	34
Filterite	3000/11356	169	1.92	0.35	18
Fulflo	3000/11356	222	2.52	0.38	15
Keystone	3000/11356	222	2.52	0.53	21

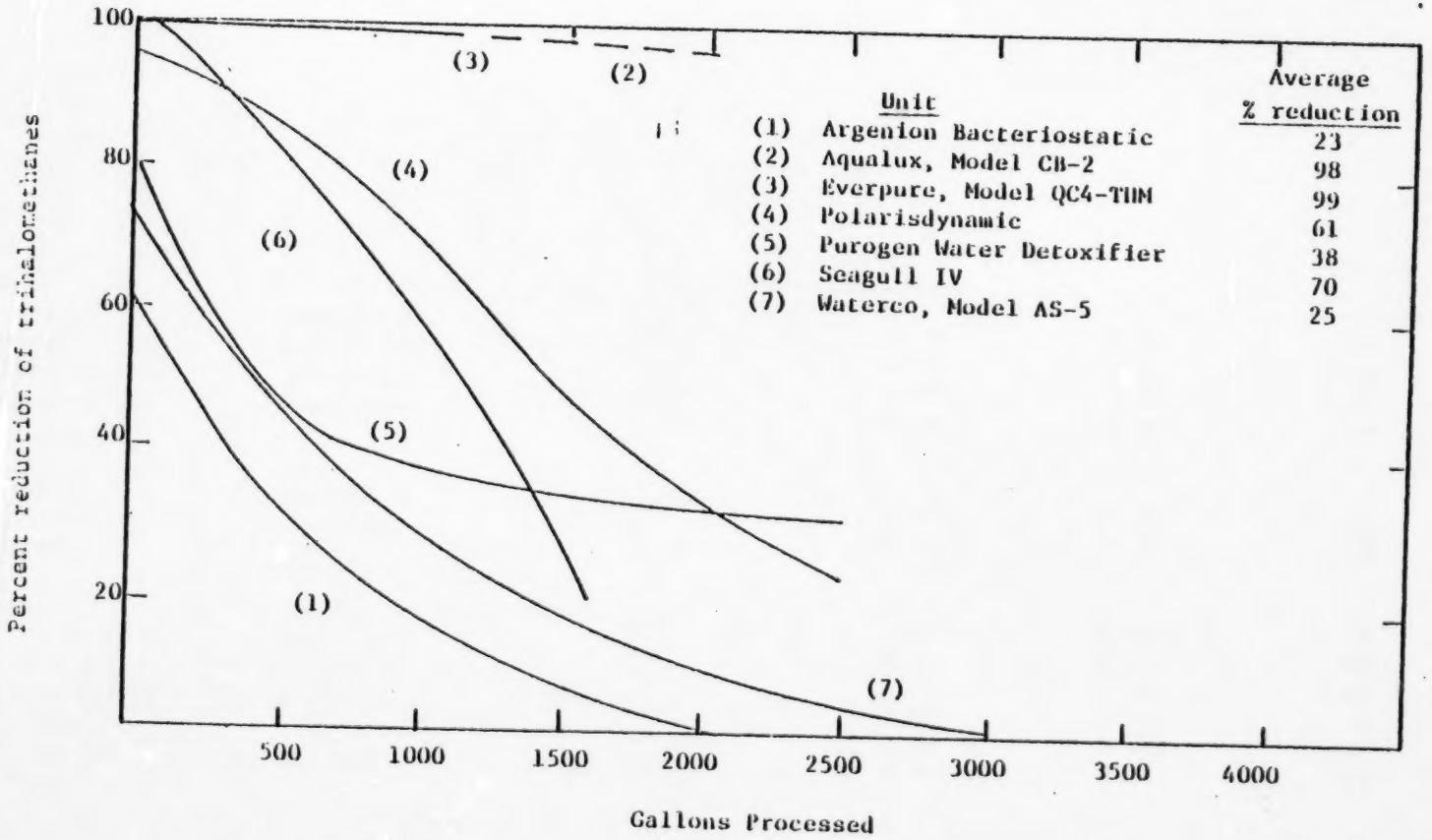


Figure 4. Summary performance of line-bypass carbon units for THM removal.

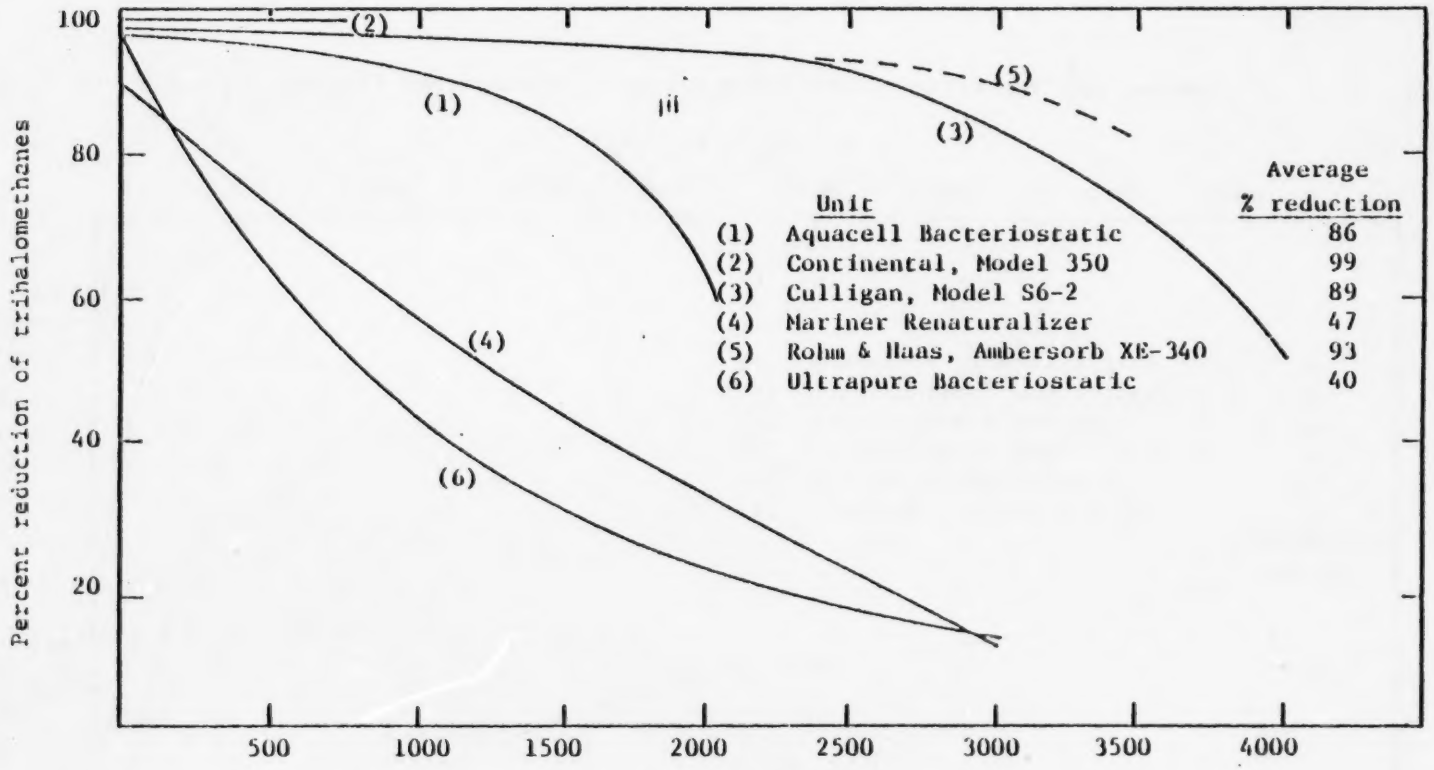


Figure 4 (continued).

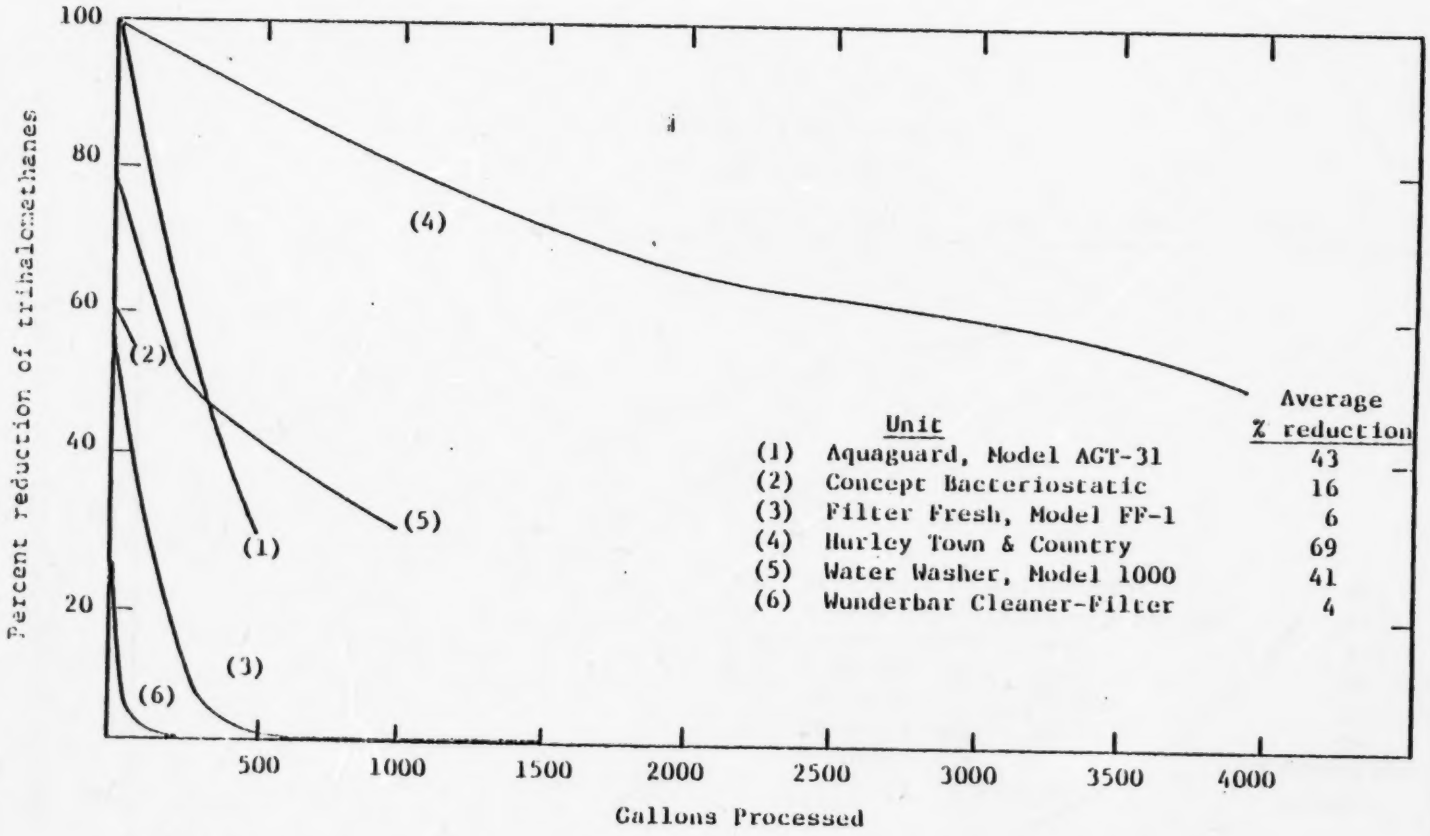


Figure 5. Summary performance of faucet-mount carbon units for THM removal.

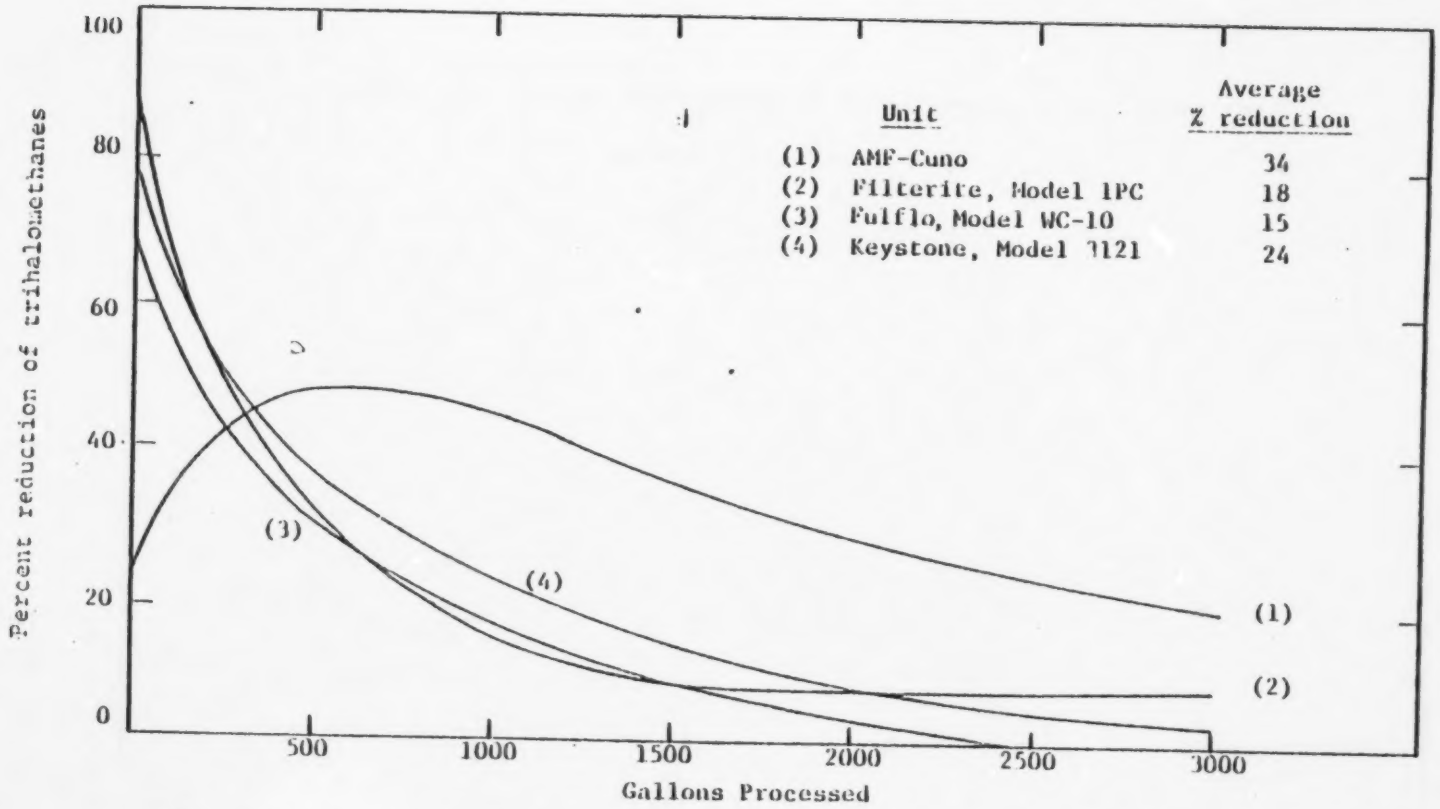


Figure 6. Summary performance of stationary carbon units for THM removal.

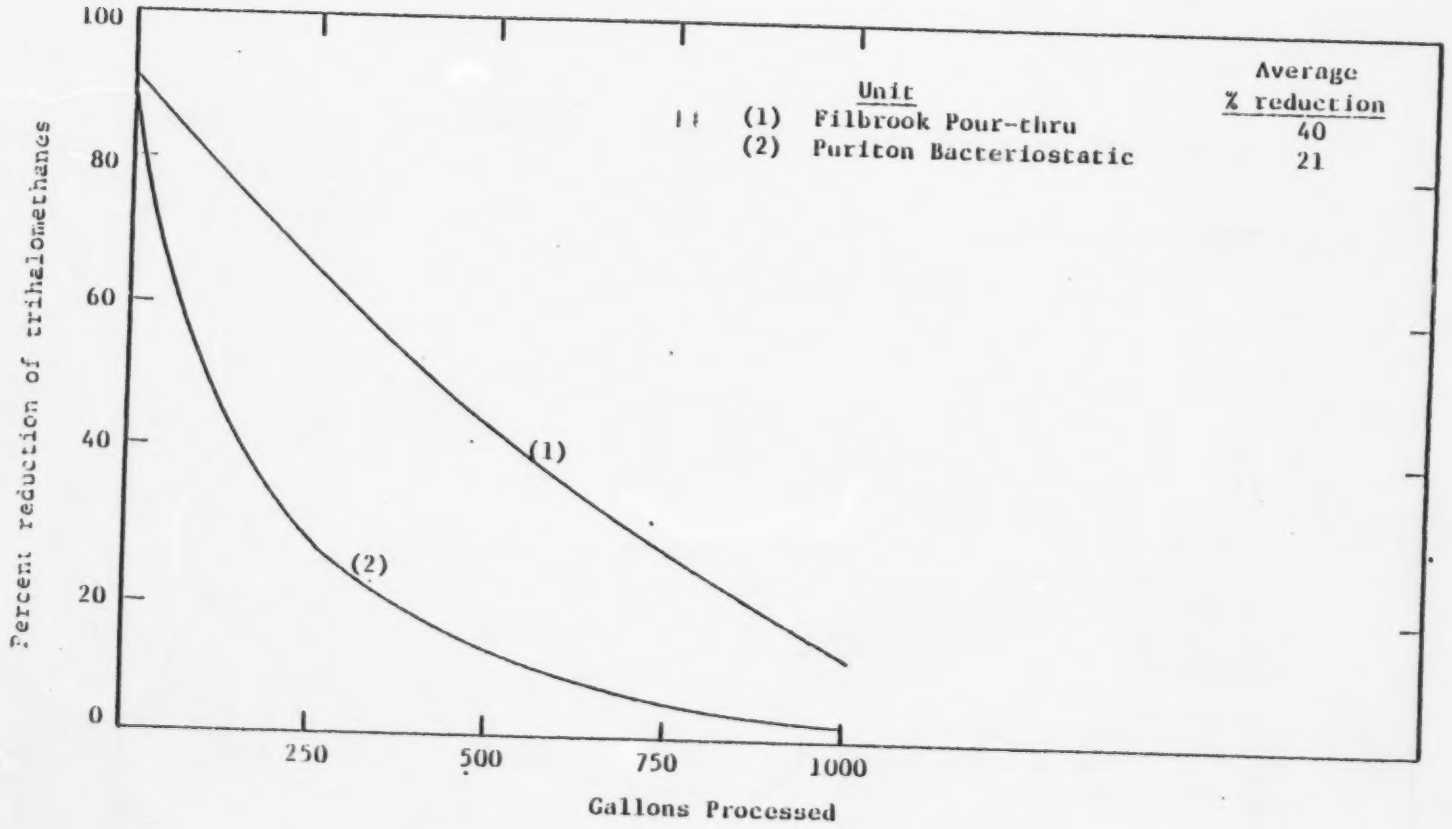


Figure 7. Summary performance of pour-through carbon units for THM removal.

The existence of such small amounts of CCl_4 in tap water during the period of unit testing did not justify the calculation of percent average reduction of CCl_4 for the test units. Therefore, CCl_4 concentrations were summed with THM concentrations when determining percent THM reduction. The original THM removal data for each trial of each unit are presented in Tables S12 through S86 and Figures S6 through S30 of "Phase 2 Supplemental Data."

Nonpurgeable Total Organic Carbon Removal

NPTOC provides a gross measure of organic material in water. Since these constituents are nonpurgeable (exhibit low volatility), they are classifed as relatively high-molecular-weight and/or more polar species. In previous discussion, it was noted that adsorptive capacity (surface area available) and rate of adsorption were dependent on a variety of factors including molecular weight and polarity. Consequently, it was predicted that removal of these nonpurgeable organic species would not be as efficient as the adsorption of THM if carbon were selected on the basis of its ability to reduce low-molecular-weight, chlorinated species.

The summary performance of each unit for NPTOC removal is reported in Tables 6 and 7 and Figures 8 through 11. NPTOC reduction was determined by using plots and calculations of the same type used for THM reduction. Major reductions of NPTOC were not observed; only two units reduced NPTOC by more than 50 percent of the influent water concentration during the lifetime of the unit. One of these units contained a large amount of carbon per rated capacity and had the greatest empty bed contact time of 3 min (Continental); the other unit employed two cartridges containing carbon, binder, and proprietary materials (Everpure). In general, units containing more activated carbon removed more NPTOC than similar smaller units. All units except Concept and Filter Fresh removed a greater percentage of THM than NPTOC from influent tap water. Most units reduced influent NPTOC levels by 6 to 31 percent.

Some NPTOC data points deviated significantly from the general population. It is emphasized that these data points may be valid because one aspect of carbon units is that unloading under stress occurs and may result in the transfer of collected matter to the product water in these "spent" units. Three units in this study consistently exhibited no NPTOC removal. The inlet NPTOC of New Orleans tap water ranged from 1.8 to 3.5 ppm during the Phase 2 study. The original data of NPTOC removal for each trial of each unit are presented in Tables S12 through S86 and Figures S31 through S55 of "Phase 2 Supplemental Data."

MICROBIOLOGICAL PARAMETERS

Potential uncontrolled bacterial growth and accompanying by-product release have been major concerns associated with the use of home water treatment units based on sorption by activated carbon. While numerous reports have addressed this concern, the conclusions have varied widely. For example, Fiore and Babineau (22) concluded that both filtered and unfiltered water responded bacteriologically to the same extent when left standing overnight. They also reported that use of activated carbon in the treatment of well water presented no additional bacteriological problems. By contrast, Wallis, et al. (23) reported substantial growth rates of bac-

TABLE 6. SUMMARY PERFORMANCE: NONPURGEABLE TOTAL ORGANIC CARBON REMOVAL DURING RATED LIFETIME FOR LINE-BYPASS UNITS

Unit	Rated capacity (gallons/liters)	Average influent concentration (ppm)	Total influent load (g)	Amount removed by activated carbon (g)	Amount removed by activated carbon (%)
Argenion	2000/7571	2.74	20.7	N/A	N/A
Aquacell	2000/7571	2.43	18.4	4.23	23
Aqualux	2000/7571	2.15	16.3	3.75	23
Continental	720/2725	2.21	6.01	5.23	87
Culligan	4000/15142	2.16	32.7	9.16	28[a]
Everpure	1000/3785	2.15	8.15	4.48	55
Mariner	3000/11356	2.45	27.9	5.86	21
Polarisdynamic	2500/9464	2.70	25.5	4.59	18
Purogen	2500/9464	2.43	23.0	1.38	6
Rohm & Haas[b]	3500/13249	2.15	28.5	1.71	6
Seagull IV	1600/6057	2.18	13.2	3.96	30
Ultrapure	3000/11356	2.58	29.3	5.86	20
Waterco	3000/11356	2.61	29.6	N/A	N/A

[a]Value obtained from estimated curve.
N/A No consistent NPTOC removal.

[b]Test unit is not commercially available; unit contains Ambersorb XE-340, an experimental absorbent material.

TABLE 7. SUMMARY PERFORMANCE: NONPURGEABLE TOTAL ORGANIC CARBON REMOVAL DURING RATED LIFETIME FOR FAUCET-MOUNT, STATIONARY AND POUR-THROUGH UNITS

Unit	Rated capacity (gallons/liters)	Average influent concentration (ppm)	Total influent load (g)	Amount removed by activated carbon (g)	Amount removed by activated carbon (%)
Faucet-mount					
Aquaguard	500/1893	2.17	4.10	0.49	12
Concept	40/151	2.90	0.44	0.08	18
Filter Fresh	1200/4542	3.02	13.7	0.82	6
Hurley T & C	4000/15142	2.67	40.5	12.6	31
Water Washer	1000/3785	2.61	9.87	1.09	11
Wunderbar	200/757	2.87	2.17	N/A	N/A
Pour-through					
Filbrook	1000/3785	2.89	10.9	1.53	14
Puriton	1000/3785	2.91	11.0	0.66	6
Stationary					
AMF-Cuno	3000/11356	2.28	25.9	1.81	7
Filterite	3000/11356	2.03	23.0	1.84	8
Fulflo	3000/11356	2.74	31.1	3.42	11
Keystone	3000/11356	2.83	32.1	2.89	9

N/A No consistent NPTOC removal.

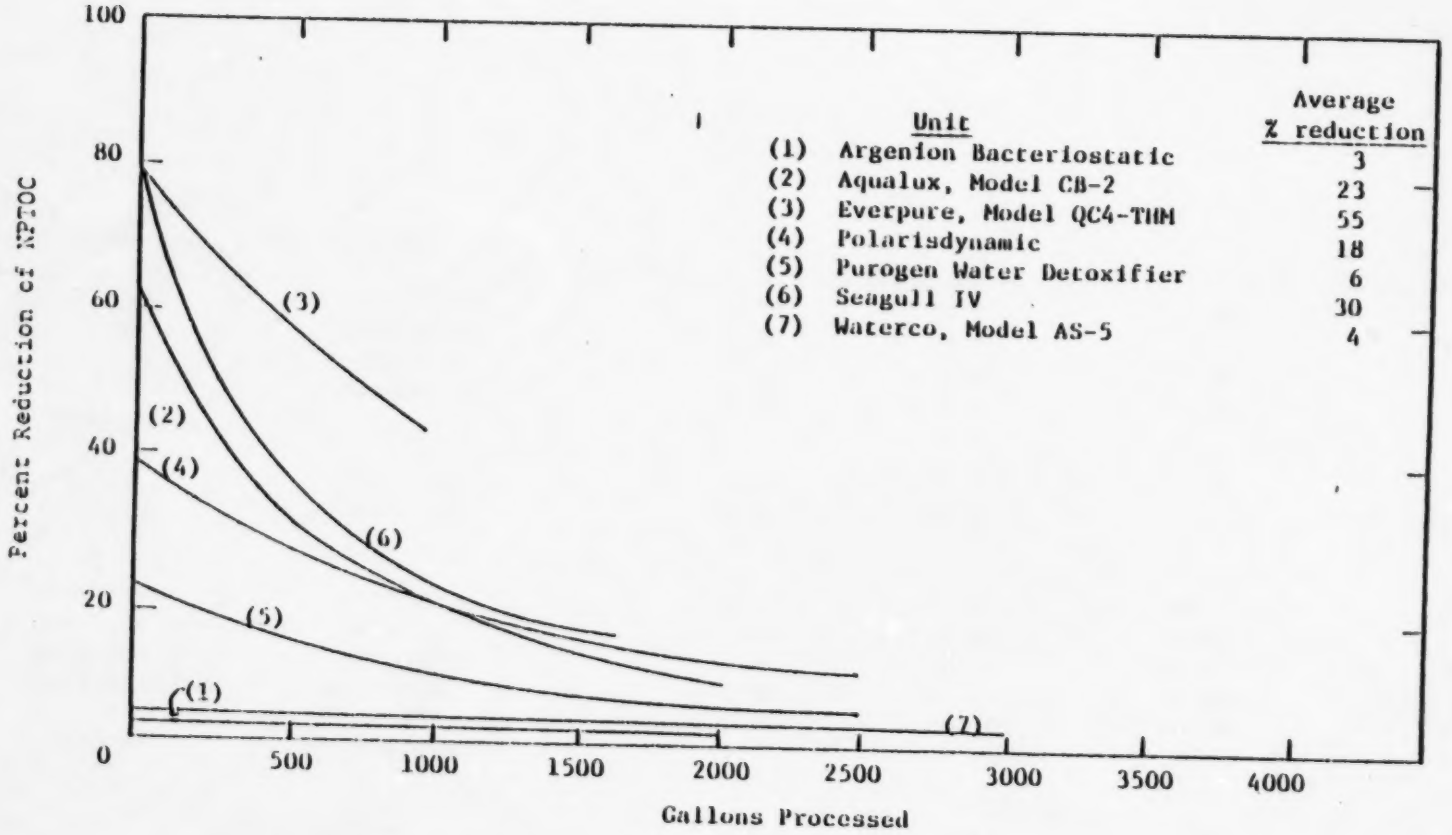


Figure 8. Summary performance of line-bypass carbon units for NPTOC removal.

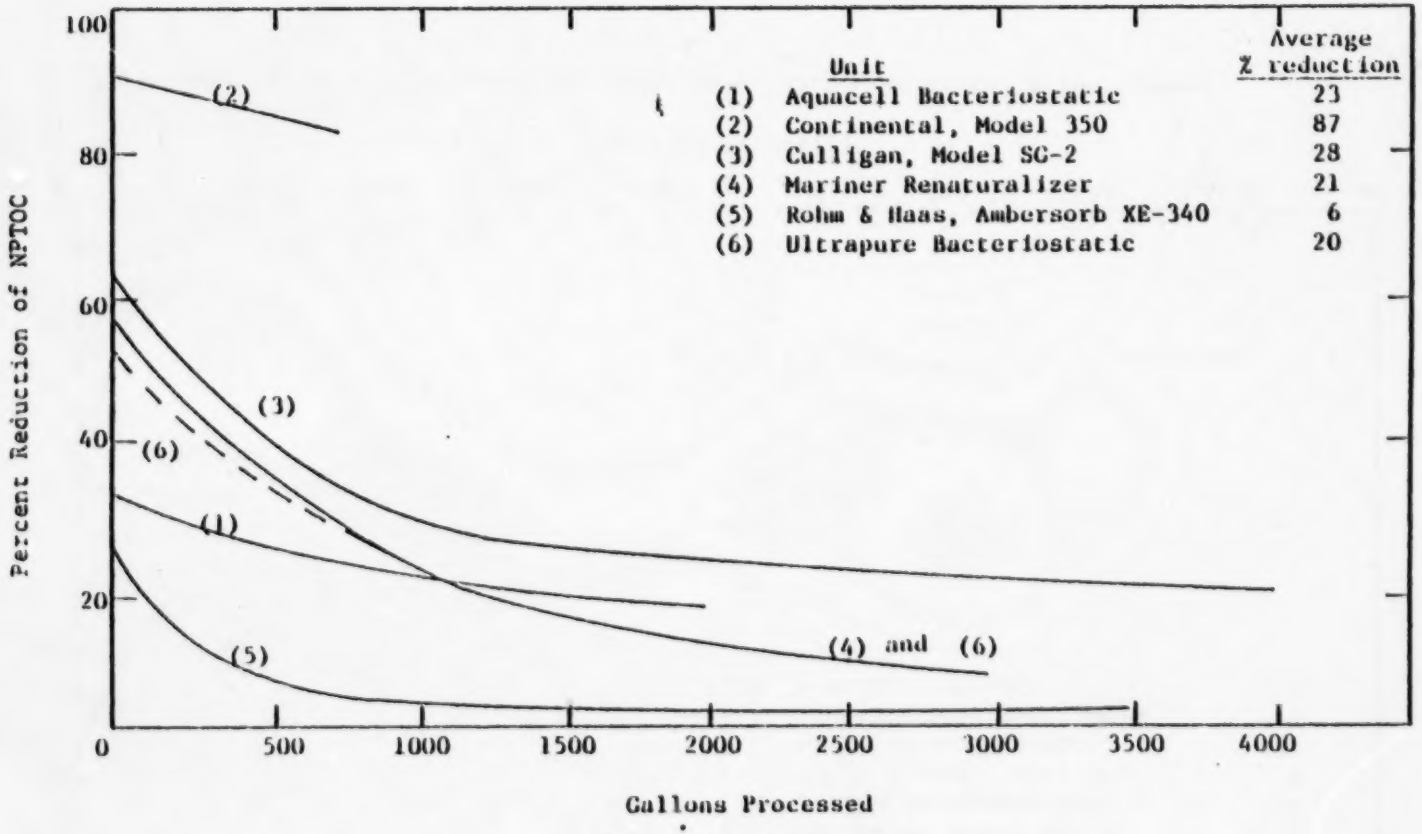


Figure 8 (continued).

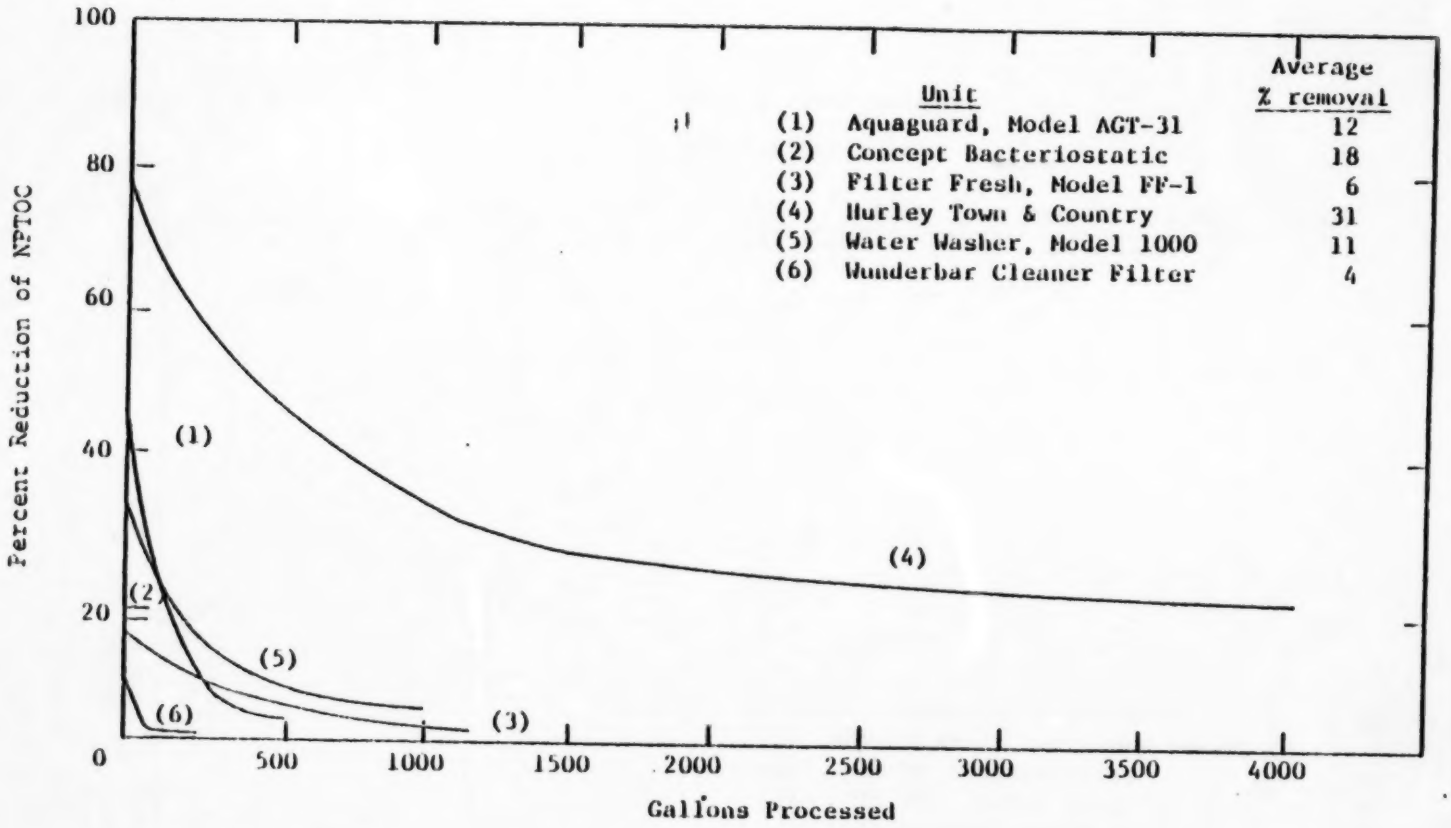


Figure 9. Summary performance of faucet-mount carbon units for NPTOC removal.

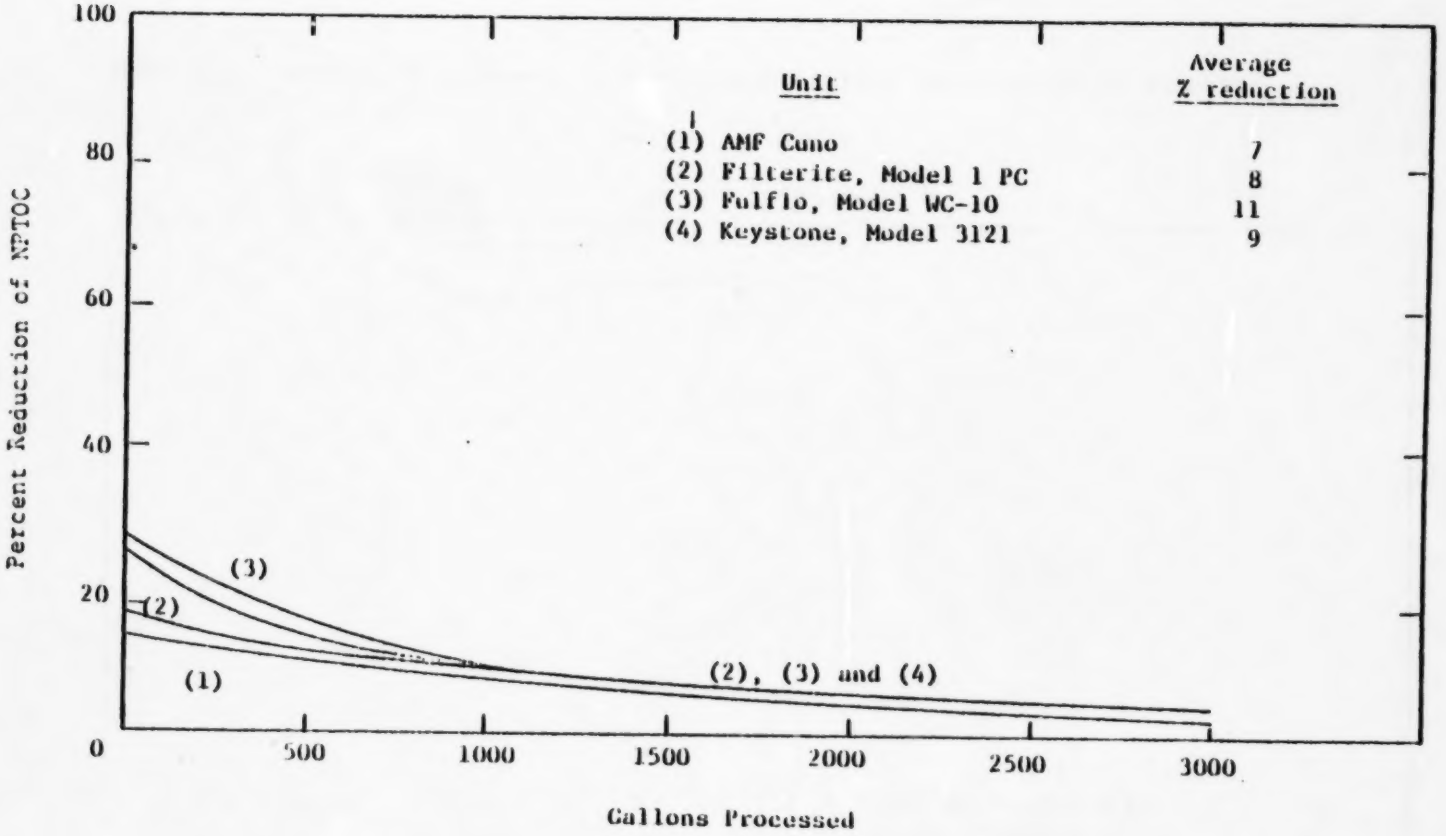


Figure 10. Summary performance of stationary carbon units for NPTOC removal.

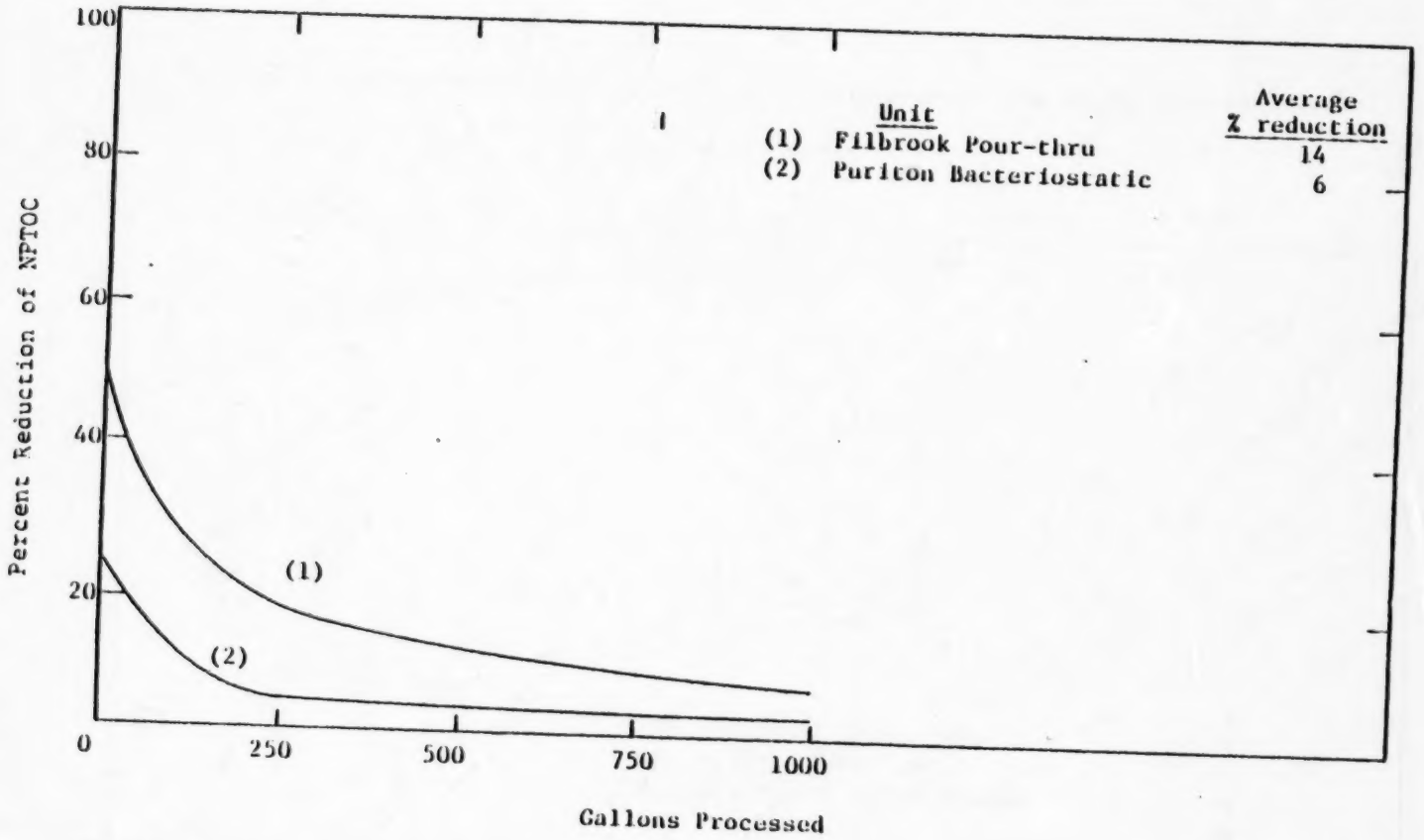


Figure 11. Summary performance of pour-through carbon units for NPTOC removal.

teria supported on activated carbon and attributed this growth to the localization of both seed bacteria and nutrients in the carbon particle. Consequently, marked bacterial growth during quiescent overnight periods may occur, resulting in large bacterial counts in the "first waters" effluent samples. Johnston and Burt (24) tried to verify the Wallis conclusion and to determine the fate of pathogenic bacteria using the coliform strain for their tests. Their results indicated that pathogenic bacteria (as represented by the coliform group) do not flourish in the filter environment. They concluded, "Bacteria indigenous to tap water are able to multiply quite well on compounds concentrated from tap water by charcoal filters; however, other types of bacteria such as coliform bacteria may not fare as well."

The preceding studies suggest that bacteria may multiply under conditions found in a home water treatment unit attached to a drinking water tap. There are numerous parameters which may minimize this growth; e.g., free chlorine levels, water usage, temperature, type of material adsorbed on the carbon, and impregnation of the carbon with silver. Many manufacturers incorporate silver in a complex, reduced-salt form within the activated carbon of the home water treatment units. The silver salt is believed to be released at a rate sufficient to suspend bacterial growth without exceeding maximum contaminant levels (50 ppb) for silver. Units of this type must be registered by the EPA under the Federal Insecticide, Fungicide, and Rodenticide Act.

Standard Plate Count (SPC) Results

The standard plate count procedure provides a means of assessing the number of aerobic and facultative anaerobic heterotrophic bacteria in water. The SPC is an empirical determination because no one set of nutritive, chemical, and physical conditions can satisfy the requirements of all bacteria in water samples. Some bacteria are usually present in drinking water and are considered to be nonpathogenic under normal home-use situations. However, the concern has been expressed that high exposure to some normally nonpathogenic organisms can result in risk to some persons. The coliform group of bacteria was also monitored during this study. However, no coliforms were found in New Orleans tap water and/or test-unit effluents.

Summary control-loop and test-unit effluent SPC results for the various types of home units are presented in Tables 8 through 10. The SPC results were divided into three populations: 1) test-unit effluent levels one or more log units less than control-loop levels (population B1); 2) test-unit effluent levels within $\pm$ one log unit of control-loop levels (population B2); and 3) test-unit effluent levels one or more log units greater than control-loop levels (population B3).

The data sets in Tables 8 through 10 note that all units had data sets in population B3, ranging from 13 to 73 percent of total data sets, whereas many units did not have data sets in population B1. In fact, data sets in population B1 ranged only from 2 to 21 percent of total data sets for respective units. The majority of units had their largest portion of data sets in population B2, ranging from 8 to 81 percent of total data sets for respective units. The pattern of data sets for individual units was variable, with reversals from populations B1 to B3 or vice versa occurring between consecutive sampling events. These SPC data indicated moderate and

TABLE 8. SUMMARY OF STANDARD PLATE COUNT DATA FOR LINE-BYPASS TEST UNITS

Category of Results	Argenion**	Aquacell**	Aqualux**	Continental*	Culligan*	Everpure*	Mariner**
Total number and (percent) of comparable data sets	16 (100)	14 (100)	14 (100)	15 (100)	15 (100)	10 (100)	16 (100)
Population B1[a] (percent)	1 (6)	1 (7)	0 (0)	0 (0)	1 (7)	0 (0)	2 (12)
Population B2[b] (percent)	9 (56)	6 (43)	9 (64)	5 (33)	9 (60)	5 (50)	7 (44)
Population B3[c] (percent)	6 (38)	7 (50)	5 (36)	10 (67)	5 (33)	5 (50)	7 (44)
Average effluent silver concentration for all test runs (µg/l)	8	3	4	NA	NA	NA	12
Range of SPC 1/ml:							
test-unit effluent	60-18000	0-4400	0-6900	0-9300	9-4300	260-8800	1-800
control loop	<10-4500	0-8900	0-930	0-930	3-5900	0-940	0-1900

*Does not contain silver; no silver analysis performed.
**Contains silver - impregnated carbon and was analyzed for silver.
NA - not applicable.

[a]Population B1 = test-unit effluent more than one log unit below control loop.

[b]Population B2 = test-unit effluent within ± one log unit of control loop.

[c]Population B3 = test-unit effluent more than one log unit above control loop.

TABLE 8 (continued).

Category of Results	Polarisdynamic**	Purogen*	Rohm & Haas*	Seagull IV*	Ultrapure**	Waterco**
Total number and (percent) of comparable data sets	17 (100)	15 (100)	14 (100)	15 (100)	15 (100)	16 (100)
Population B1[a] (percent)	0 (0)	0 (0)	1 (7)	1 (6)	1 (6)	0 (0)
Population B2[b] (percent)	6 (35)	12 (80)	9 (64)	4 (27)	5 (34)	9 (56)
Population B3[c] (percent)	11 (65)	3 (20)	4 (29)	10 (67)	9 (60)	7 (44)
Average effluent silver concentration of all test runs (µg/l)	11	NA	NA	NA	3	3
Range of SPC 1/ml:						
test-unit effluent	100-11000	3-6700	18-36000	<10-15000	<10-55000	90-25000
control loop	<10-3700	6-6600	0-6600	0-7900	4-4200	<10-4500

*Does not contain silver; no silver analysis performed.
**Contains silver - impregnated carbon and was analyzed for silver.
NA - not applicable.

[a]Population B1 = test-unit effluent more than one log unit below control loop.

[b]Population B2 = test-unit effluent within ± one log unit of control loop.

[c]Population B3 = test-unit effluent more than one log unit above control loop.

TABLE 9. SUMMARY OF STANDARD PLATE COUNT DATA FOR FAUCET-MOUNT TEST UNITS

Category of Results	Aquaguard*	Concept**	Filter Fresh*	Hurley*	Water Washer**	Wunderbar*
Total number and (percent) of comparable data sets	15 (100)	14 (100)	14 (100)	16 (100)	15 (100)	17 (100)
Population B1[a] (percent)	1 (6)	2 (15)	3 (21)	0 (0)	1 (7)	0 (0)
Population B2[b] (percent)	10 (67)	9 (64)	1 (8)	10 (63)	3 (20)	9 (53)
Population B3[c] (percent)	4 (27)	3 (21)	10 (71)	6 (37)	11 (73)	8 (47)
Average effluent silver concentration for all test runs (µg/l)	NA	3	NA	NA	2	NA
Range of SPC 1/ml:						
test-unit effluent	0-13000	<10-7900	<10-81000	35-14000	30-31000	<10-12000
control loop	3-240	<10-8100	<10-3800	<10-15000	20-7600	<10-2300

*Does not contain silver; no silver analysis performed.
**Contains silver - impregnated carbon and was analyzed for silver.
NA - not applicable.

[a]Population B1 = test-unit effluent more than one log unit below control loop.

[b]Population B2 = test-unit effluent within ± one log unit of control loop.

[c]Population B3 = test-unit effluent more than one log unit above control loop.

TABLE 10. SUMMARY OF STANDARD PLATE COUNT DATA FOR POUR-THROUGH AND STATIONARY TEST UNITS

Category of Results	Pour-through		Stationary			
	Filbrook*	Puriton**	AMF-Cuno*	Filterite*	Fulflo*	Keystone*
Total number and (percent) of comparable data sets	16 (100)	15 (100)	16 (100)	15 (100)	16 (100)	16 (100)
Population B1[a] (percent)	0 (0)	2 (13)	1 (6)	0 (0)	2 (12)	0 (0)
Population B2[b] (percent)	13 (81)	11 (74)	10 (63)	4 (27)	7 (44)	13 (81)
Population B3[c] (percent)	3 (19)	2 (13)	5 (31)	11 (73)	7 (44)	3 (19)
Average effluent silver concentration for all test runs (µg/l)	NA	7	NA	NA	NA	NA
Range of SPC 1/ml:						
test-unit effluent	<10-8000	<10-25000	4-5000	14-150000	<10-7500	<10-5400
control loop	<10-6800	<10-12000	0-4200	0-9800	<10-10000	<10-1400

*Does not contain silver; no silver analysis performed.

**Contains silver - impreganted carbon and was analyzed for silver.

NA - not applicable.

[a]Population B1 = test-unit effluent more than one log unit below control loop.

[b]Population B2 = test-unit effluent within ± one log unit of control loop.

[c]Population B3 = test-unit effluent more than one log unit above control loop.

variable effects of activated carbon on bacterial levels in test-unit effluent waters as compared with tap water sampled under similar conditions (control-loop samples). Figures S56 through S80 in the "Phase 2 Supplemental Data" show the average of the logs of test-unit effluent SPC minus control-loop SPC plotted at various intervals throughout the rated capacity (gallons) of individual units. These plots fail to define any consistent pattern; however, the SPC1 (48 hr) plots closely parallel the SPC2 (120 hr) plots.

Endotoxin Results

Endotoxins are derived from the cell walls of dead bacteria (the gram-negative bacteria which comprise a major part of the SPC bacterial population) and thus represent an additional measure of biological activity in drinking water. The injection of endotoxins into the blood stream of animals or humans elevates body temperatures (pyrogenic activity); however, endotoxins are normally introduced into humans through the gastrointestinal tract rather than directly into the blood. In a study by Wolf, et al. (25), the injection of drinking waters of varying endotoxin content (1.2 - 2.5 ng/ml) from 27 water supplies (utilizing activated-carbon treatment) failed to demonstrate pyrogenic activity in any of 28 rabbits tested. The maximum endotoxin concentrations of selected public water supplies reported in the preceding study are comparable with the endotoxin levels found in the present GSRI study.

Summary control-loop and test-unit effluent endotoxin results are presented in Tables 11 through 13. The endotoxin results were divided into three populations: 1) test-unit effluent levels less than one-half control-loop levels (population E1); 2) test-unit effluent levels within 1/2 and 2X control-loop levels (population E2); and 3) test-unit effluent levels greater than 2X control-loop levels (population E3). The endotoxin results are similar to SPC results. All test units had data sets in population E3, ranging from 7 to 65 percent of total data sets, while data sets in population E1 ranged from 0 to 40 percent of total data sets. The majority of test units had data sets in population E2 as the largest portion of respective sets, ranging from 20 to 93 percent of total data sets. While SPC ranged over five orders of magnitude, endotoxin concentrations were all within two orders of magnitude. Endotoxin data seem to indicate that while activated carbon increased endotoxin levels, there were reversals in consecutive sampling points, and the overall effect of activated carbon was minimal. One factor which may limit the detection of endotoxins is the ability of carbon to adsorb endotoxin materials.

Miscellaneous Results

Standard plate count and endotoxin concentrations were determined on the used and unused carbons from all test models (Table S113). Bacteria were rinsed from the pulverized carbon samples into sterile, pyrogen-free water, and water samples were analyzed. These tests indicated the presence of low SPC and endotoxin levels in the unused filter material. SPC and endotoxin levels on the used carbon were in the same range as test-unit effluent levels; influent-side analyses for SPC were higher for some units than the effluent-side, but this pattern was not consistent. Coliform

TABLE 11. SUMMARY OF ENDOTOXIN DATA FOR LINE-BYPASS TEST UNITS

Category of Results	Argenton**	Aquacell**	Aqualux**	Continental*	Culligan*	Everpure*	Mariner**
Total number and (percent) of comparable data sets	15 (100)	12 (100)	14 (100)	16 (100)	13 (100)	12 (100)	15 (100)
Population E1[a] (percent)	4 (27)	3 (25)	2 (14)	0 (0)	3 (23)	0 (0)	3 (20)
Population E2[b] (percent)	6 (40)	6 (50)	7 (50)	7 (44)	8 (62)	7 (58)	7 (47)
Population E3[c] (percent)	5 (33)	3 (25)	5 (36)	9 (56)	2 (15)	5 (42)	5 (33)
Average effluent silver concentration for all test runs (ng/l)	8	3	4	NA	NA	NA	12
Range of endotoxin (ng/ml):							
test-unit effluent	1.1-7.3	0.7-6.4	1.1-6.3	1.6-7.6	0.3-6.9	3.6-5.7	1.3-7.0
control loop	<0.1-5.0	1.4-7.3	1.2-4.2	1.0-4.9	1.4-5.2	1.5-3.2	1.4-10.8

*Does not contain silver; no silver analysis performed.
**Contains silver - impregnated carbon and was analyzed for silver.
NA - not applicable.

[a]Population E1 = test-unit effluent less than 1/2X control loop.

[b]Population E2 = test-unit effluent within 1/2X and 2X control loop.

[c]Population E3 = test-unit effluent greater than 2X control loop.

TABLE 11 (continued).

Category of Results	Polarisdynamic**	Purogen*	Rohm & Haas*	Seagull IV*	Ultrapure**	Waterco**
Total number and (percent) of comparable data sets	17 (100)	15 (100)	15 (100)	12 (100)	13 (100)	16 (100)
Population E1[a] (percent)	0 (0)	1 (7)	1 (7)	3 (25)	2 (15)	3 (19)
Population E2[b] (percent)	6 (35)	10 (67)	9 (60)	6 (50)	8 (62)	5 (31)
Population E3[c] (percent)	11 (65)	4 (26)	5 (33)	3 (25)	3 (23)	8 (50)
Average effluent silver concentration of all test runs (µg/l)	11	NA	NA	NA	3	3
Range of endotoxin (ng/ml):						
test-unit effluent	2.2-26.9	1.0-10.0	1.2-6.9	0.9-6.8	1.1-8.0	0.9-29.8
control loop	<0.1-14.1	<0.1-3.9	1.3-4.5	1.7-6.5	1.2-7.3	0.2-14.1

*Does not contain silver; no silver analysis performed.
**Contains silver - impregnated carbon and was analyzed for silver.
NA - not applicable.

[a]Population E1 = test-unit effluent less than 1/2X control loop.

[b]Population E2 = test-unit effluent within 1/2X and 2X control loop.

[c]Population E3 = test-unit effluent greater than 2X control loop.

TABLE 12. SUMMARY OF ENDOTOXIN DATA FOR FAUCET-MOUNT TEST UNITS

Category of Results	Aquaguard*	Concept**	Filter Fresh*	Hurley*	Water Washer**	Wunderbar*
Total number and (percent) of comparable data sets	15 (100)	14 (100)	14 (100)	17 (100)	14 (100)	17 (100)
Population E1[a] (percent)	0 (0)	0 (0)	0 (0)	1 (6)	2 (14)	4 (23)
Population E2[b] (percent)	7 (47)	13 (93)	8 (57)	7 (41)	5 (36)	11 (65)
Population E3[c] (percent)	8 (53)	1 (7)	6 (43)	9 (53)	7 (50)	2 (12)
Average effluent silver concentration for all test runs (µg/l)	NA	3	NA	NA	2	NA
Range of endotoxin l/ml:						
test-unit effluent	3.0-6.8	2.0-8.6	2.5-8.4	1.5-25.4	2.8-8.9	1.7-7.6
control loop	1.3-7.3	1.9-7.1	1.2-4.8	1.6- 4.5	0.1-12.7	1.3-8.4

*Does not contain silver; no silver analysis performed.
**Contains silver - impregnated carbon and was analyzed for silver.
NA - not applicable.

[a]Population E1 = test-unit effluent less than 1/2X control loop.

[b]Population E2 = test-unit effluent within 1/2X and 2X control loop.

[c]Population E3 = test-unit effluent greater than 2X control loop.

TABLE 13. SUMMARY OF ENDOTOXIN DATA FOR POUR-THROUGH AND STATIONARY TEST UNITS

Category of Results	Pour-through		Stationary			
	Filbrook*	Puriton**	AMF-Cuno*	Filterite*	Fulflo*	Keystone*
Total number and (percent) of comparable data sets	14 (100)	16 (100)	14 (100)	15 (100)	15 (100)	15 (100)
Population E1[a] (percent)	2 (14)	2 (13)	4 (29)	2 (13)	4 (27)	6 (40)
Population E2[b] (percent)	6 (43)	9 (56)	9 (64)	9 (60)	3 (20)	4 (27)
Population E3[c] (percent)	6 (43)	5 (31)	1 (7)	4 (27)	8 (53)	5 (33)
Average effluent silver concentration for all test runs (µg/l)	NA	7	NA	NA	NA	NA
Range of endotoxin l/ml:						
test-unit effluent	1.2-6.5	1.6-8.0	1.1-6.5	0.8-8.0	1.6-9.6	0.9-6.5
control loop	1.0-5.5	1.4-6.4	1.1-7.8	1.2-4.3	1.0-6.4	1.4-5.5

*Does not contain silver; no silver analysis performed.
**Contains silver - impreganted carbon and was analyzed for silver.
NA - ot applicable.

[a]Population E1 = test-unit effluent less than 1/2X control loop.

[b]Population E2 = test-unit effluent within 1/2X and 2X control loop.

[c]Population E3 = test-unit effluent greater than 2X control loop.

bacteria were not detected in any of the carbon samples. All test data for bacterial evaluations are contained in "Phase 2 Supplemental Data," Tables S88 through S112 and Figures S56 through S80.

Statistical Analyses

Silver Effects on SPC and Endotoxin--

Under test conditions with tap water, effluents from silver-impregnated activated carbon units had silver levels within the Interim Primary Drinking Water maximum contaminant level of 50 ppb. It is noted that New Orleans tap water has a pH of 9.5 which limited silver release (average silver levels varied from 2-12 ppb in silver-unit effluents). The effect of silver-impregnated activated carbon on SPC and endotoxin levels was revealed by the analysis of data presented in Tables 14 through 17. Table 14 indicates that units incorporating silver had virtually the same percentage of data sets in all populational categories as did nonsilver units. Likewise, endotoxin data from Table 15 indicate approximately the same percentage of data sets in the various categories for silver and nonsilver units. Consequently, these data suggest that no significant bacteriostatic effect is exerted by silver units challenged with New Orleans tap water.

Tables 16 and 17 present a statistical analyses of the SPC and endotoxin data. The effluent water samples from silver and nonsilver units are categorized as follows: (A) two-day stagnation sample; (B) five-day stagnation sample; (C) running-water sample; and (D) overnight-stagnation sample. Mean and standard deviation (SD) values for SPC and endotoxin determinations were obtained from all effluent samples within each category (Table 16). Statistical methods which give a yes or no answer were employed to answer questions concerning the significance of data obtained from silver (S population) and nonsilver (NS population) units.

So that a yes or no answer can be given, a significance level, i.e., 95 or 99 percent, is chosen to express the probability that the answer is correct. Careful judgment must be exercised in selecting the confidence level. If the confidence level is too severe (such as 99.9 percent), a significant effect may be missed and a true hypothesis rejected. On the other hand, if too much latitude is allowed (such as 80 percent), an insignificant difference may be judged important and a false hypothesis accepted. A 95 percent confidence level was used in this study.

To determine any bacteriostatic effects of silver units, two questions were asked. First, is the variance (SD^2) within SPC and/or endotoxin S populations comparable with the variance within respective NS populations at the 95 percent confidence level? This question was answered by the F test in Table 17. An answer of no indicates that the variance within one population is too large to be compared with the variance within the other population at the specified confidence level. An answer of yes from the F test permits the second question to be statistically meaningful: Is the mean value of respective SPC and/or endotoxin S populations significantly different from the mean value of respective NS populations? The student t test answered this question, and the answers are presented in Table 17. The observation of a significant difference between two mean values of respective populations (SPC or endotoxin) must be interpreted with care because the absolute values (level) of the parameters being tested determine what "effects" these parameters may exert on a particular system.

TABLE 14. SUMMARY OF STANDARD PLATE COUNT DATA: SPC1 AND SPC2

Category of results	Silver units				Nonsilver units			
	SPC1		SPC2		SPC1		SPC2	
	Number of sets	Percent of total	Number of sets	Percent of total	Number of sets	Percent of total	Number of sets	Percent of total
Total sets	152	100	143	100	225	100	221	100
Population B1[a]	10	6	7	5	10	4	9	4
Population B2[b]	74	49	74	52	121	54	117	53
Population B3[c]	68	45	62	43	94	42	95	43
Range of SPC1:								
test units	0 - 55000				0 - 150000			
control loop	0 - 15000				0 - 15000			
Range of SPC2:								
test units	0 - 39000				0 - 73000			
control loop	0 - 11000				0 - 11000			

[a]Population B1 = test-unit effluent one log unit below control loop.

[b]Population B2 = test-unit effluent within ± one log unit of control loop.

[c]Population B3 = test-unit effluent one log or more above control loop.

TABLE 15. SUMMARY OF ENDOTOXIN DATA: SILVER UNITS VERSUS NONSILVER UNITS

Category of results	Silver units		Nonsilver units	
	Number of sets	Percent of total	Number of sets	Percent of total
Total sets	146	100	219	100
Population E1[a]	21	15	31	14
Population E2[b]	72	49	111	51
Population E3[c]	53	36	77	35
Range of Endotoxin (ng/ml):				
test-unit effluent	0.7-29.8		0.3-25.4	
control loop	<0.1-14.1		<0.1- 8.4	

[a]Population E1 = test-unit effluent less than 1/2X control loop.

[b]Population E2 = test-unit effluent within 1/2X and 2X control loop.

[c]Population E3 = test-unit effluent greater than 2X control loop.

TABLE 16. STANDARD PLATE COUNT AND ENDOTOXIN DATA FROM TEST-UNIT EFFLUENTS: SILVER UNITS VERSUS NONSILVER UNITS

Parameter	Silver units				Nonsilver units			
	A	B	C	D	A	B	C	D
$Log_{10}(SPC1) = x$								
Number of data points	20	19	32	79	29	29	62	119
Mean of x	3.01	3.31	2.36	2.78	3.05	2.99	2.09	2.62
SD of x	0.93	0.88	1.08	0.83	1.04	1.02	0.95	0.93
Relative SD of x (%)	31	27	46	30	34	34	46	35
$Log_{10}(SPC2) = y$								
Number of data points	20	19	29	79	30	29	58	117
Mean of y	3.06	3.30	2.38	2.80	2.99	3.04	2.28	2.70
SD of y	0.99	0.77	0.96	0.77	0.96	1.04	0.89	0.87
Relative SD of y (%)	32	23	40	27	32	34	39	32
Endotoxin (ng/ml) = z								
Number of data points	20	19	32	79	30	28	62	120
Mean of z	3.7	4.2	4.1	5.1	4.7	3.8	3.6	4.2
SD of z	1.8	1.9	2.4	5.3	2.2	1.6	1.6	2.8
Relative SD of z (%)	48	46	57	103	47	41	44	67

A = 2-day stagnation sample
B = 5 day stagnation sample
C = running-water sample
D = overnight-stagnation sample

TABLE 17. STATISTICAL COMPARISON OF STANDARD PLATE COUNT AND ENDOTOXIN DATA FROM TEST-UNIT EFFLUENTS

Parameter	Mean value of type of analysis			
	A	B	C	D
Log_{10}(SPC1)	3.01 (S)[a]	3.31 (S)	2.36 (S)	2.78 (S)
	3.05 (NS)[a]	2.99 (NS)	2.09 (NS)	2.62 (NS)
F test 95% confidence level[b]	yes	yes	yes	yes
t test 95% confidence level[c]	no	no	no	no
Log_{10}(SPC2)	3.06 (S)	3.30 (S)	2.38 (S)	2.80 (S)
	2.99 (NS)	3.04 (NS)	2.28 (NS)	2.70 (NS)
F test 95% confidence level	yes	yes	yes	yes
t test 95% confidence level	no	no	no	no
Endotoxin (ng/ml)	3.7 (S)	4.2 (S)	4.1 (S)	5.1 (S)
	4.7 (NS)	3.8 (NS)	3.6 (NS)	4.2 (NS)
F test 95% confidence level	yes	yes	no	no
t test 95% confidence level	yes	no	NA	NA

A = 2-day stagnation sample
B = 5-day stagnation sample
C = running-water sample
D = overnight-stagnation sample

[a](S) = units with silver; (NS) = units with no silver

[b]The F test is a comparison of variances (i.e., yes, indicates that the variances of the two populations are comparable).

[c]The t test is used to test the hypothesis that two means do or do not differ significantly (i.e., No indicates that the two populational means do not differ significantly).

NA - not applicable

The only populations which differed significantly were the endotoxins from two-day stagnation samples; nonsilver units produced the higher mean value of the two populations (4.7 versus 3.7 ng/ml). Other than this one result, the rest of the data in Tables 14 through 17 imply that silver-impregnated activated-carbon units challenged with New Orleans tap water do not exert a significant bacteriostatic effect on the drinking water. It is re-emphasized that New Orleans tap water has a pH of about 9.5 which could limit bacteriostatic effects by inhibiting silver release into the water (average silver levels were 2-12 ppb from silver-impregnated carbon units).

SPC1 versus SPC2--

Standard plate counts (SPC1) are determined by incubating plated samples for 48 hr at 35°C (9). However, this study also obtained plate counts (SPC2) from samples incubated for 120 hr at room temperature (about 25-28°C). Plate count values obtained by the two procedures were compared by using linear regression analysis. Table 18 lists the results of the linear regression analysis of $\log_{10}$(SPC1) versus $\log_{10}$(SPC2) for each type of bacterial sample in both control-loop and test-unit effluents. The correlation coefficient obtained for each type of sample (range, 0.75 to 0.94) indicates that there is moderate linear correlation between SPC1 and SPC2 values (a correlation coefficient of 1.00 means a perfect correlation). It appears that higher absolute values of SPC in test unit effluents account for slightly better correlation coefficients than those of control loop samples.

SPC1 versus endotoxin--

The correlation between SPC1 and endotoxin was determined by using linear regression analyses. Table 19 indicates that a linear correlation between $\log_{10}$(SPC1) and endotoxin was not observed at levels of SPC1 and endotoxin found in this study.

Control-loop samples versus test-unit effluents--

Table 20 presents data of statistical analyses comparing mean values of SPC and endotoxin populations from test unit effluents with the respective populations of control-loop samples. Statistical F tests and t tests (to 95 percent confidence level) were used to determine significant difference.

The SPC analyses were divided into two sets, SPC1 and SPC2, each containing four subset populations: (a) two-day stagnation; (b) five-day stagnation; (c) running water; and (d) overnight stagnation. Of the eight SPC1 and SPC2 statistical analyses, six revealed significantly higher test-unit effluent levels as compared with control-loop levels. Differences between respective SPC levels varied from 0.20 to 1.08 log units. The data also indicated that increasing degrees of stagnation (from running water to 5-day stagnation) result in higher SPC levels for both test-unit effluents and control-loop samples; in fact, SPC bacteria increased more rapidly in control-loop samples than in test-unit effluents.

The corresponding endotoxin statistical results were less clear-cut with only two out of four tests showing significantly higher levels in test-unit effluents as compared to control-loop samples. Differences between respective endotoxin levels ranged from 0.7 to 1.4 ng/ml. Endotoxin levels (populational means) were virtually the same in both running water and 5-day stagnation samples for respective test-unit effluents and control-loop samples.

TABLE 18. LINEAR REGRESSION ANALYSIS OF LOG_{10}(SPC1) VERSUS LOG_{10}(SPC2)

Parameter	Control-loop samples				Test-unit effluents			
	A	B	C	D	A	B	C	D
Number of data points	39	34	71	183	49	48	87	196
Mean of x	2.32	2.68	1.39	1.57	3.04	3.12	2.14	2.63
Mean of y	2.32	2.93	1.45	1.72	3.07	3.13	2.29	2.73
Variance of x	1.00	1.37	0.58	0.68	0.95	0.92	1.03	0.89
Variance of y	0.79	0.77	0.67	0.60	0.83	0.87	0.82	0.68
Slope of line[a]	0.67	0.65	0.92	0.82	0.81	0.91	0.75	0.76
Intercept of line	0.77	1.20	0.16	0.42	0.62	0.30	0.69	0.75
SD of x data	1.01	1.19	0.76	0.83	0.99	0.97	1.02	0.94
SD of y data	0.90	0.89	0.83	0.83	0.92	0.94	0.91	0.83
Correlation coefficient	0.75	0.86	0.85	0.83	0.86	0.94	0.84	0.86

$x = \log_{10}(SPC1)$
$y = \log_{10}(SPC2)$

[a]Equation of line: $y = mx + b$
where: m = slope of line
b = intercept of line

A = 2-day stagnation sample
B = 5-day stagnation sample
C = running-water sample
D = overnight-stagnation sample

TABLE 19. LINEAR REGRESSION ANALYSIS OF LOG_{10}(SPC1) VERSUS ENDOTOXIN

Parameter	Control-loop samples				Test-unit effluents			
	A	B	C	D	A	B	C	D
number of data points	37	34	70	183	50	47	94	198
mean of x	2.33	2.62	1.41	1.66	2.97	3.02	2.18	2.64
mean of y	2.95	2.58	2.58	2.63	3.80	3.55	3.39	7.76
variance of x	1.10	1.37	0.58	0.69	1.14	1.12	0.98	0.92
variance of y	2.76	2.53	3.46	3.03	3.03	2.76	3.17	3.17
slope of line[a]	-.39	0.15	-0.11	0.03	1.11	0.08	0.20	0.10
intercept of line	4.36	2.49	3.29	3.20	0.93	3.74	3.28	4.32
SD of x data	1.05	1.17	0.76	0.83	1.07	1.06	0.99	0.96
SD of y data	1.66	1.59	1.86	1.74	1.74	1.66	1.78	1.78
correlation coefficient	-.20	0.15	-0.07	0.01	0.52	0.05	0.14	0.02

x = log_{10}(SPC1)

y = Endotoxin (ng/ml)

A = 2-day stagnation sample
B = 5-day stagnation sample
C = running-water sample
D = overnight-stagnation sample

[a]Equation of line: $y = mx + b$
where: m = slope of line
b = intercept of line

TABLE 20. STATISTICAL COMPARISON OF STANDARD PLATE COUNT AND ENDOTOXIN DATA FROM TEST-UNIT EFFLUENT AND CONTROL-LOOP SAMPLES

Parameter	Mean value			
	A	B	C	D
Log_{10}(SPC1)	3.04 (TUE)[a]	3.12 (TUE)	2.18 (TUE)	2.69 (TUE)
	2.32 (CL)	2.68 (CL)	1.42 (CL)	1.61 (CL)
F test 95% confidence level[b]	yes	yes	no	yes
t test 95% confidence level[c]	yes	yes	NA	yes
Log_{10}(SPC2)	3.02 (TUE)	3.13 (TUE)	2.31 (TUE)	2.75 (TUE)
	2.32 (CL)	2.93 (CL)	1.47 (CL)	1.72 (CL)
F test 95% confidence level	yes	yes	yes	yes
t test 95% confidence level	yes	no	yes	yes
Endotoxin (ng/ml)	4.3 (TUE)	4.0 (TUE)	3.8 (TUE)	4.6 (TUE)
	3.3 (CL)	2.9 (CL)	3.1 (CL)	3.2 (CL)
F test 95% confidence level	yes	no	yes	no
t test 95% confidence level	yes	NA	yes	NA

A = 2-day stagnation sample
B = 5-day stagnation sample
C = running-water sample
D = overnight-stagnation sample

[a](TUE) = test unit effluent; (CL) = control loop

[b]The F test is a comparison of variances (i.e., yes, indicates that the variances of the two populations are comparable).

[c]The t test is used to test the hypothesis that two means do or do not differ significantly (i.e., No indicates that the two populational means do not differ significantly).

NA - not applicable

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